A STUDY OF ASIAN PARANASAL SINUS ANATOMY USING TRIPLANAR COMPUTED TOMOGRAPHY SCANS

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This study has been made possible through the Health Ministry Service Development Fund (FY2003) that provided a grant of $500,000 to investigate if the use of Image Guidance in Endoscopic Sinus Surgery made a difference in patient satisfaction outcome and in reducing surgical complications. The tri-planar CT scans used in this study were the pre-operative CT scans of patients enrolled into the Health Ministry Service Development Fund (FY2003) study.

My supervisor, Clinical Professor Yeoh Kian Hian , has inspired many rhinologists in Asia to find out if paranasal anatomy in Asians was different to that of published Western series with his much cited publication "The optic nerve in the posterior ethmoid in Asians." published in Acta Otolaryngologica in 1994 in which he and his co-author Clinical Associate Professor Henry K.K. Tan pointed out that the sphenoethmoid cell existed in two out of every three Asian patients as compared to one out of every three Caucasian patients. Their work gave me encouragement to start this study as an important clinical consideration resulted from their anatomical study.

MJ Citardi MD of the Cleveland Clinic Foundation discussed the concept of using triplanar CT views to study the anatomy of the paranasal sinuses and of the frontal sinus in particular. The classification of frontal sinus cells using triplanar CT views as proposed by Citardi and his co-workers was adopted for this study. I wish to thank Dr. Citardi for sharing the concepts of his work with me and the privilege of using the CBYON workstation used in the studies of Citardi and his co-workers whilst I was at the Cleveland Clinic Foundation on Ministry of Health Manpower Development grant to study Image Guided Systems in Rhinology.

I thank Staff Nurse Jane Lo for helping me in all matters related to our surgical navigation equipment, including set up and retrieval of patient data.

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SUMMARY

This study specifically focuses on the frontal sinus, the presence of *concha bullosa*, Haller cells, the sphenoethmoid cell (Onodi) and the degree of pneumatization of the sphenoid sinus in relation to the internal carotid artery and optic nerve. It is based on simultaneous views of any single point in the paranasal sinuses in the coronal, axial and sagittal planes.

History of the study of paranasal sinus anatomy reflects the relative obscurity of the study of this region in relation to the development of study of anatomy in general. It was not until the development of endoscopic sinus surgery that a resurgence of interest in paranasal sinus anatomy was established in the mid 1980's.

An understanding of the embryology of the paranasal sinuses explains the anatomical position and physiological function of the lateral nasal wall structures from which the natural history of pathological processes may be deduced.

Anatomic terminology and nomenclature has been adopted from the consensus statements made by the Anatomic Terminology Group at the International Conference on Sinus Disease: Terminology, Staging, and Therapy, held in the United States in Princeton, New Jersey, in July 1993 and published in the Annals of Otology, Rhinology and Laryngology Supplement in October 1995.

Definitions of radiological anatomy are adopted from the published papers of Lee and Batra.(2004) This author had the opportunity to be involved in the preliminary discussions of these papers with Martin Citardi MD whilst visiting the Cleveland Clinic on HMDP to study Image Guided Surgery Systems in 2002.

As this study is based on interpretation of tri-planar CT views based on surgical navigation protocols, the subject of surgical navigation is covered to enhance understanding of the process of pre-operative evaluation and how intra-operative images showing key anatomic landmarks were obtained.

Materials and methods of this study are presented and followed with a discussion on the clinical importance of the findings of this study.

Several conclusions based on observation, with caveats, are made regarding the findings of this study as compared to studies of Caucasian and Asian subjects using similar (CT scan interpretation – single plane coronal and triplanar) and dissimilar (cadaveric dissection) methods of study.

Sixty four illustrations cross referenced to this thesis include three types of views : tri-planar planning (pre-operative), tri-planar operative views and sagittal cadaveric dissection specimens. Relevant endoscopic views during surgery and of cadaveric specimens are also included. These illustrations provide a visual explanation to the radiological definitions used in this thesis and also show important radiological anatomical landmarks correlated to the intra-operative situation and to cadaveric dissection specimens.

CHAPTER 1

THESIS CONCEPT.

This thesis is based primarily on a study of triplanar Computed Tomography (CT) projections of the paranasal sinuses of patients who underwent diagnostic and pre-operative CT scans for complaints arising from sinus and nasal disorders.

This study is able to provide a more accurate description of radiological anatomy than previously published studies that were principally based on coronal plane CT sections alone. Computer technology allowing for simultaneous viewing of the same single point in three sections i.e. coronal, sagittal and axial provides a more accurate means of interpretation of radiological anatomy. Most authors now will agree that it is not possible to interpret the configuration of frontal sinus cells without the sagittal section.

The findings, due to patient selection, reflect anatomy of diseased paranasal sinuses. Disease of the majority of paranasal sinuses studied were in the anterior aspect of the paranasal sinuses. Three recent published series[1,2,3] using triplanar CT projections of undiseased paranasal sinuses are used as comparisons to the results of this study. There is no published work in current otolaryngology literature on the study of diseased sinuses using triplanar CT projections.

The concept for this thesis was proposed by M.J. Citardi MD whom this author met at the Cleveland Clinic in 2002 whilst on attachment to learn about Image Guidance Systems. Dr. Citardi is well known internationally for his work in surgical navigation. The author was involved in discussions regarding concepts involving interpretation of triplanar CT projections and was able to use the CBYON workstation employed for the work that resulted in the three publications that will be quoted for comparison. These three publications have been chosen for comparison as the method of study of paranasal sinuses i.e. the use of triplanar CT scans, is the same as in this study. However, as these three publications were based on triplanar CT views of disease free paranasal sinuses in a Caucasian majority population, variability of comparison cannot be conclusively ascertained as to be due to ethnic or anterior paranasal sinus disease differences.

As this thesis is an anatomical study, the author has opted to use illustrations from triplanar CT views correlated with actual operative views, endoscopic views and cadaveric dissection specimens to demonstrate the anatomical structures named in this thesis. Anatomical structures named in the text are referenced to these illustrations.

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CHAPTER 2

HISTORY

Leonardo da Vinci's drawings in the 15th century clearly showed the paranasal sinuses , although several sources credit Berengar del Carpi, an Italian surgeon of the 16th century, as the first person to describe the paranasal sinuses.

The maxillary, frontal, and sphenoid sinuses were first described by Vesalius, an Italian anatomist in the 16th century who stated they contained nothing but air.

The absence of the sphenoid sinus in young children and its subsequent development with maturity was noted by Fallopius, a contemporary of Vesalius. He also noted that the frontal and maxillary sinuses are not present in newborns but begin to develop in the first year of life.

The anatomy of the maxillary sinuses was described in detail by Nathaniel Highmore in the 17th century, The maxillary sinus was noted to be occasionally absent by Morgagni in the 18th century

Numerous ideas about the function of the paranasal sinuses were proposed then. Some interesting proposals are as follows. That air was held in the sinuses before entering the brain and that secretions from the brain, lubricants of the eye and animal spirits were stored in the sinuses. The sinuses were thought to add resonance to the voice and to act as a reservoir for mucous. Children had runny noses because their sinuses were simply not big enough to hold secretions.

Modern rhinologic anatomy as we know it now is based on the work of Zuckerkandl of Vienna and Adolf Onodi of Budapest who were 19th century anatomists and the anatomic studies of Mosher and Van Alyea published in early 20th century.

Lateral nasal wall anatomy from an endoscopic perspective was described by Walter Messerklinger in Graz, Austria which led to the publication of "Endoscopy of the Nose" in the English language in 1978. Lang and Ritter published detailed anatomical studies including a range of measurements of thickness and distances within the paranasal sinuses from cadaveric studies.

A resurgence of interest in paranasal sinus anatomy paralleling the development of endoscopic sinus surgery started in the mid 80's when the students of Walter Messerklinger , Heinz Stammberger and Gerald Wolf lectured and established courses on this subject in English. David Kennedy brought the interest in endoscopic sinus surgery to USA and developed upon the subject. Kennedy's collaborator, radiologist Zinreich first described paranasal sinus anatomy based on computed tomography.

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CHAPTER 3

EMBRYOLOGY

At the 9th week of fetal development the ethmoid turbinates (middle, superior and supreme) (FIG 3) are begins with 6 major furrows. Each furrow is separated by ridges which have an ascending and descending portion. The adult nasal turbinates form from the fusion or disappearance of these ridges.

The inferior turbinate develops from a separate bone, the maxilloturbinal.

The agger nasi is a remnant of the ascending portion of the first ethmoturbinal.

The uncinate process develops from the descending portion of the first ethmoturbinal.

The middle turbinate develops from the second ethmoturbinal, the superior turbinate develops from the third ethmoturbinal, and the supreme turbinate develops from the fourth and fifth ethmoturbinals.

The depression between the first and second ethmoturbinal becomes the ethmoid infundibulum, and its superior ascending part becomes frontal recess. The superior meatus develops from the second furrow.

The significance of these embryologic structures are appreciated during endoscopic sinus surgery as they are encountered from anterior to posterior. The first basal lamella corresponds to the uncinate process, the second basal lamella corresponds to the ethmoid bulla, the third basal lamella corresponds to the basal lamella of the middle turbinate known as the ground lamella that separates the anterior and posterior ethmoid sinuses, and the fourth basal lamella corresponds to basal lamella of the superior turbinate.

The ethmoid sinuses first appear during the fourth fetal month. Secondary pneumatization, which is pneumatization occurring after birth, is completed by the second year of life.

At birth, the ethmoids are present in the same quantity but smaller in size as an adult . The anterior ethmoid cells develop under the middle meatus, and the posterior ethmoid cells develop in the superior meatus. The approximate adult volume of the ethmoid cells is 15 ml.

The turbinates originate from the lateral nasal wall during development, and each has its own basal lamella. As the basal lamella of the third ethmoturbinal, which separates the anterior and posterior ethmoid complexes, the middle turbinate basal lamella is anatomically and physiologically the most important of the basal lamellas. Because there is more than one basal lamella, however, when the term basal lamella is used, the turbinate with which it is associated must be specified.

The role of the basal lamella of the middle turbinate as the division between anterior and posterior ethmoid complexes is underscored by the French terminology, *racine cloisonnante du cornet moyen*, which means the dividing root of the middle turbinate.

The ethmoid bulla, uncinate process, and semilunar hiatus make their appearance as a blind pouch at the apex of the hiatus during the fourth month of fetal development and are consistently identified in the middle meatus of newborns.

The sphenoid sinus begins development during the 3rd fetal month as the sphenoethmoidal recess constricts and draws the superior concha upward. Secondary pneumatization does not begin until 10 years of age. The approximate adult volume of the sphenoid sinus is 7.5 ml.

At birth, the maxillary sinus is spherical or pyramidal in shape and appears as a shallow sack in the lateral nasal wall.

Between ages 1 and 4, the maxillary sinus extends to the infraorbital nerve laterally and inferiorly it extends to the inferior turbinate.

By age 7, the maxillary sinus grows past the infraorbital nerve and extends below the middle of the inferior meatus.

After age twelve, the maxillary sinus extends to the floor of the nose, and in adults the sinus extends below the floor of the nose. The maxillary sinus may have accessory septa.

The roof of the maxillary sinus ranges from 0.1 to 7.0 mm thick medial to the infraorbital canal, and 0.1 to 1.1 mm thick lateral to the infraorbital canal. In an adult, the volume of the maxillary sinuses is approximately 15 ml.

The frontal sinus develops from the anterior most portion of the middle meatus and secondary pneumatization does not occur until the second year of life. The frontal sinus is bordered by its anterior and posterior tables, the orbital roof inferiorly, and an intersinus septum medially. Prior to one year of age, the frontal sinus appears as a frontal cell which drains into the ethmoid infundibulum. Between ages 1 and 4, the sinus begins to develop into the frontal bone. Between ages 4 and 7, lateral and medial expansion occur. By age 12, the frontal sinus is tetrahedron shaped and continues to develop into the 4th decade. While volume of an average adult frontal sinus is 7 ml, the frontal sinus size may range from total aplasia to total aeration of the frontal bone. Asymmetry of the frontal sinuses is common. In Lang's specimens the anterior table ranged from 0.5 to 12.5 mm thick and the posterior table between 0.3 and 4.0 mm thick.

In Van Alyea’s classification of frontal sinus cells, a Type IV cell is described as an air cell that is found entirely in a frontal sinus and which has no connection or drainage pathway into the middle meatus. As the frontal sinus occurs through pneumatization superiorly from the middle meatus, a Type IV cell almost certainly arises from the middle meatus and may represent a developmental anomaly of the drainage pathway detaching itself off from its origin and draining directly into the frontal sinus. If direct drainage into the frontal sinus fails, then a mucocele will form. The relative rarity of a Type IV frontal cell attests to its status as a developmental anomaly.

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CHAPTER 4

ANATOMIC TERMINOLOGY AND NOMENCLATURE

The description of anatomy and nomenclature below is based on the consensus statements made by the Anatomic Terminology Group at the International Conference on Sinus Disease: Terminology, Staging, and Therapy, held in the United States in Princeton, New Jersey, in July 1993.

The participants of this group were Prof Heinz R. Stammberger, Facilitator , Maj William E. Bolger, Prof Peter A. R. Clement, Prof Werner Hosemann, Frederick A. Kuhn, Donald C. Lanza, Donald A. Leopold, Toshio Ohnishi, Prof Desiderio Passali, Steven D. Schaefer, Prof M. R. Wayoff, S. James Zinreich.

It adheres to precepts of nomenclature outlined early in this century: an anatomic name must be used universally to denote a single structure and any attribute that the name connotes must always be present. These terms are intended to provide clear communication among otorhinolaryngologists and serve as a basis for discussion among anatomists. Terminology is in English and based on Latin nomenclature. An attempt has been made to reconcile or eliminate duplication, redundancy, and overlap in terminology that have arisen over the past century. A key concept is that the ethmoid complex is divided into anterior and posterior sections by the basal lamella of the middle turbinate.

These consensus statements are internationally accepted as standard terminology and this author makes no attempts to modify this standard terminology or to change the presentation from its original form. Instead, additional comments relevant to this study have been inserted into this classic paper and anatomical structures named are cross referenced to illustrations in this thesis.

ETHMOID COMPLEXES

The structures of the lateral nasal wall and paranasal sinuses fall into two anatomically and physiologically distinct categories, the anterior and posterior ethmoid complexes. The basal lamella of the middle turbinate (FIG 35) is the clear and distinct separation between the two ethmoid complexes, according to definition, patterns of mucociliary secretion transport, and embryologic development. Cells and clefts that open and drain anteriorly and inferiorly to this lamella belong to the anterior ethmoid complex; those that open or drain posteriorly or superiorly, with the exception of the sphenoid sinus, belong to the posterior ethmoid complex. The expressions middle ethmoid and middle ethmoid cells should not be used, because in terms of anatomy, physiology, or function, no structure represents the middle of the ethmoid complex.

BASAL LAMELLA OF MIDDLE TURBINATE

This structure is actually the third basal lamella of the ethmoturbinals. (FIG 34, 35) The most anterior and superior insertion of the middle turbinate is adjacent to the *crista* *ethmoidalis* of the maxilla. The posterior end is attached to the *crista ethmoidalis* of the perpendicular process of the palatine bone (*lamina perpendicularis*).

The area between comprises three parts . The anterior third of the middle turbinate inserts vertically into the skull base at the lateral edge of the *lamina cribrosa*. The middle third turns laterally across the skull base to the *lamina papyricea*, where it turns inferiorly. The most posterior segment becomes horizontal.

The insertion of the middle turbinate thus lies in three different planes. The anterior segment lies sagittally, attaching to the lateral lamella of the *lamina cribrosa* opposite its lamina lateralis. The middle segment is fixed to the *lamina papyricea* in an almost frontal plane. The posterior segment is attached to the *lamina papyricea*, the medial wall of the maxillary sinus, or both, to form the roof of the posterior third of the middle meatus.

The stability of the middle turbinate accrues largely from its fixation along three planes. The anterior and posterior portions, which are vertical and horizontal, respectively, are part of the basal lamella of the middle turbinate. The middle section, also part of the basal lamella, is not necessarily a smooth surface. Cells or well-pneumatized clefts of the anterior ethmoid can indent this plate dorsally, giving it a posterosuperior orientation. When a retrobullar recess is well developed, anterior ethmoid cells can reach back almost to the sphenoid sinus. Conversely, cells of the posterior ethmoid or the superior meatus can create an anterior bulge in the midsection of the basal lamella. (FIG 4)

The term basal is preferable to ground to avoid misnomers such as grand lamella, which lend themselves to misconceptions and confusion.

ANTERIOR ETHMOID AND RELATED STRUCTURES

Uncinate Process.

The term derives from the Latin, *processes uncinatus*, meaning hooked outgrowth, and refers to a remnant of the descending portion of the first ethmoturbinal.

The uncinate process is a thin, bony leaflet that resembles a hook. (FIG 6, 7) It is oriented almost sagittally and runs from antero-superior to postero-inferior. Its concave postero-superior free margin is parallel to the anterior surface of the ethmoid bulla. The uncinate process attaches to the perpendicular process (*lamina perpendicularis*) of the palatine bone posteriorly and the ethmoid process of the inferior turbinate with bony spicules inferiorly. The convex anterior margin ascends to the lacrimal bone, and sometimes to the skull base or *lamina papyricea*, (FIG 31,32,33) remaining in contact with the bony lateral nasal wall. When curved medially to a greater than usual extent, the free margin of the uncinate process may protrude into, and sometimes even out of, the middle nasal meatus. The uncinate process may attach to the middle turbinate superiorly, too, when curved medially in its superior most portion. In rare cases, the superior part of the uncinate process may attach with several "fingers" to the middle turbinate, the skull base, and the lateral nasal wall as well.

Agger Nasi.

The term comes from the Latin for nasal mound and refers to the most superior remnant of the first ethmoturbinal, which persists as a mound or crest immediately anterior and superior to the insertion of the middle turbinate. An *agger nasi* cell results when this area of the lateral nasal wall under goes pneumatization.(FIG 4,5,6) Depending on the degree of pneumatization, *agger nasi* cells may reach laterally to the lacrimal fossa and cause narrowing of the frontal recess.

Ethmoid Bulla.

From the Latin, *bulla ethmoidalis*, (FIG 7, 16 , 21) where bulla means a hollow, thin-walled, bony prominence, the name refers to the largest and most non-variant air cells in the anterior ethmoid complex. It is formed by pneumatization of the bulla lamella, or second ethmoid basal lamella, and is like a bleb on the lamina papyricea. The bulla lamella can form the posterior wall of the frontal recess if it reaches the roof of the ethmoid. Failure to reach the skull base, however, results in formation of the suprabullar recess, an aerated space of varying dimensions between the bulla lamella and the skull base. This recess may at times form an air cell. This is described as a suprabullar cell, (FIG 21) a type of air cell which forms the posterior group of air cells of the frontal recess. When an air cell ascends from above the bulla anteriorly beyond the frontal recess into the frontal sinus, it is known as a frontal bulla cell.(FIG 16)

The ethmoid bulla, (FIG 16, 21) created when the second basal lamella of the ethmoturbinals is pneumatized, is sometimes called a promontory in the literature. In the absence of pneumatization, it does not exist. The traditional anatomic term for a persisting and non-pneumatized second basal lamella is *torus ethmoidalis*. The suggestion to change the name *torus bullaris* was rejected by the Anatomic Terminology Group because the term is oxymoronic. Torus describes a solid structure, and bullaris refers to a pneumatized structure. The term *torus lateralis* does not specifically denote the non-pneumatized bulla lamella.

<u>Suprabullar and Retrobullar Recess (*Sinus Lateralis*).</u>

The Latin term *recessus suprabullaris et retrobullaris* is the same as the sinus lateralis of Grunwald. The suprabullar recess may extend into a retrobullar recess (FIG 7) if the posterior wall of the bulla lamella is not in contact with the basal lamella of the middle turbinate. When well developed, this space is bordered superiorly by the ethmoid roof, laterally by the lamina papyricea, inferiorly by the roof of the ethmoid bulla, and posteriorly by the basal lamella of the middle turbinate. Anteriorly, it is separated from the frontal recess only when the bulla lamella reaches the skull base . Otherwise, the suprabullar recess opens into the frontal recess. The suprabullar and retrobullar recess also can be approached medially and inferiorly through the *hiatus semilunaris superior*. (FIG 21)

This space does not have a single opening for ventilation and drainage, and therefore does not satisfy the criteria of a cell. The term recess is recommended because the space can be approached anteriorly and superiorly from the frontal recess and medially and inferiorly from the *hiatus semilunaris superior*. (FIG 21) Grunwald's term, *sinus lateralis*, is suitable anatomically, but the complete term, *sinus lateralis sinus ethmoidalis*, is necessary to differentiate it from the lateral sinus in the brain. The latter term is considered too long to be practical.

Hiatus Semilunaris Inferior.

The origin of this term is the *hiatus semilunaris inferior* of Grunwald. The *hiatus semilunaris inferior* is an anatomic plane that represents the shortest distance between the free posterior margin of the uncinate process and the corresponding anterior face of the ethmoid bulla. Typically, but not necessarily, it lies in the sagittal plane and does not represent a true space. (FIG 7, 21)

Two concepts are helpful when considering the term *hiatus semilunaris*. First, the Latin root translates directly into English as cleft, gap, or passageway; indeed, the *hiatus semilunaris inferior* is a crescent-shaped cleft. Second, the passageway is like a doorway through which one must pass to arrive at the ethmoid infundibulum, which is a three-dimensional space.

Hiatus Semilunaris Superior.

This is a second, but only vaguely defined, crescent-shaped cleft between the ethmoid bulla and the middle turbinate. The suprabullar and retrobullar recess can be entered medially and inferiorly underneath the middle turbinate through the *hiatus semilunaris superior.*

The term inferior rather than anterior is recommended for the *hiatus semilunaris* that is located between the uncinate process and the ethmoid bulla, and superior rather than posterior is recommended for the *hiatus semilunaris* that may lead into the suprabullar and retrobullar recess. When the orientation of the head conforms to that of a standing person, inferior and superior are more accurate.

Infundibulum.

The term infundibulum (plural, infundibula) (FIG 7) connotes a funnel shaped structure and comes from the Latin *infundere,* meaning to pour into. There are three different infundibula in the paranasal sinuses: the frontal, maxillary, and ethmoid. The ethmoid infundibulum is the most important pathophysiologically, and the others are notable primarily for historical perspective. The ethmoid infundibulum, from *infundibulum ethmoidale*, is a cleft or true three-dimensional space. Were a cast made of the space, it would typically resemble an inverted segment of grapefruit with the wide edge facing posteriorly.

The ethmoid infundibulum is bordered medially by the uncinate process (FIG 7) and laterally by the *lamina papyricea*.(FIG 33) The frontal process of the maxilla and the lacrimal bone may constitute parts of the lateral wall antero-superiorly, but this is rare.

Fusion with the anterior border of the uncinate process provides a connection with the inferior turbinate.

At its anterior end, the ethmoid infundibulum ends blindly in an acute angle, giving rise to the V-like shape noted in axial sections and on CT scans. (FIG 26) Posteriorly, the ethmoid infundibulum extends to the anterior face of the ethmoid bulla and opens into the middle meatus through the *hiatus semilunaris inferior.* Periosteum and mucous membrane cover bony defects in the lateral nasal wall, forming the anterior and posterior nasal fontanelles.

The maxillary sinus ostium usually can be found at the floor and lateral aspect of the infundibulum between its middle and posterior third. From the middle meatus, the natural ostium of the maxillary sinus therefore remains hidden, lateral to the uncinate process in the ethmoid infundibulum. (FIG 30)

The relationship between the ethmoid infundibulum and the skull base, especially the frontal recess, depends on the uncinate process. Superiorly, the ethmoid infundibulum may end blindly in the terminal recess, or *recessus terminalis,* (FIG 26,27) if the uncinate process bends laterally and inserts onto the *lamina papyricea*. If the uncinate process reaches to the skull base or fuses with the middle turbinate medially, the ethmoid infundibulum may pass into the frontal recess superiorly.

The frontal sinus and maxillary sinus infundibula are inside their respective sinus cavities and resemble narrowing or funneling tunnels toward their natural ostia. The border between the ethmoid infundibulum and the frontal recess is difficult to define. Embryologically, the ethmoid infundibulum and frontal recess arose from a single structure, and the variations of the uncinate process determine the relationship between the two in maturity.

The frontal infundibulum, (FIG 46) named from the Latin *infundibulum sinus frontalis* or *infundibulum frontale*, is a funnel-shaped narrowing of the inferior aspect of the frontal sinus toward the floor of the frontal sinus ostium. It is located inside the frontal sinus. The maxillary infundibulum, after the Latin infundibulum *sinus maxillaris* or *infundibulum maxillare*, is the funnel-shaped narrowing of the lumen of the maxillary sinus toward its natural ostium. (FIG 30) Typically, the lumen does not narrow significantly toward the maxillary sinus ostium.

<u>Frontal Recess.</u>

Perhaps the most complicated structure in the anterior ethmoid complex, the frontal recess is the most anterior and superior portion of the complex that leads to and communicates with the frontal sinus. (FIG 46) It is not synonymous with the nasofrontal duct.

The medial wall of the frontal recess is the most anterior and superior part of the middle turbinate. The lateral wall is mostly *lamina papyricea*. A discrete posterior margin exists only when the basal lamella of the bulla reaches the skull base, separating the frontal recess from the suprabullar recess . If the insertion of the bulla lamella reaches far anteriorly and/or the bulla is well pneumatized, the frontal recess becomes narrowed from the posterior. This may result in a tubular appearance on sagittal section, which is the reason the narrowed recess came to be known, albeit incorrectly, as the nasofrontal duct. (FIG 17).

In sagittal section, the frontal recess usually has the shape of an inverted funnel. When taken together with the frontal infundibulum, the shape resembles an hourglass, with the constricted portion being at the level of the natural ostium of the frontal sinus. The floor of the frontal recess varies so much that it has no uniform definition.

Although the anatomic definitions are clear, there is great confusion in usage among these terms. The frontal recess is the most anterior and superior part of the anterior ethmoid complex. From here, the frontal bone becomes pneumatized, resulting in a frontal sinus. Seen from above, the frontal recess narrows toward its ostium (through the frontal infundibulum). From the level of the ostium, the frontal recess then widens in the inferior and posterior direction, usually in the shape of an inverted funnel.

When this communication is narrowed from behind by the ethmoid bulla or the bulla lamella or from in front by a pneumatized *agger nasi* cell, a seeming short, duct like structure results. The bony walls of the resulting structure are not truly its own, however, so to call it a duct or other tubular structure is not anatomically correct. Its duct-like appearance on sagittal or coronal CT scans is misleading.

The formation of additional cells in the frontal recess and the infundibulum, apart from *agger nasi* cells, is highly individual. The Anatomic Terminology Group recommends that they be described according to their anatomic orientation. For example, if they reach the lacrimal sac and pneumatize into the lacrimal bone, they would be lacrimal cells of the ethmoid infundibulum or lacrimal cells of the frontal recess. A cell that pneumatizes into the frontal bone is likewise a frontal cell of the anterior ethmoid or a bulla frontalis. Terms such as threshold cell are to be avoided. A supraorbital cell is an anatomic variant that develops as an extension, from the posterior aspect, of the frontal or suprabullar recess. It is therefore called a supraorbital cell of the frontal recess or a supraorbital cell of the suprabullar recess. (FIG 12).

Standard terminology for cells in the frontal sinus has been proposed and is adopted in this study. Air cells related to the frontal sinus are divided into anterior, posterior and medial groups and are identified principally with the sagittal plane CT which were not available to the Anatomic Terminology Group in 1993. The next chapter elaborates on this proposed classification of frontal cells.

Nasal Fontanelles.

These are the areas of the lateral nasal wall in which no bone exists. (FIG 4) They are usually found immediately above the insertion of the inferior turbinate. Thus, the mucosa of the maxillary sinus and the middle meatus are separated only by a fibrous layer of periosteum. The fontanelles may be sites of accessory ostia to the maxillary sinus. (FIG 30)The anterior fontanelle is inferior and anterior to the uncinate process; the posterior fontanelle is superior and posterior to the part of the uncinate process that fuses with the medial wall of the maxillary sinus.

Roof of Ethmoid.

Lateral to the *lamina cribrosa* and to the insertion of the middle turbinate, the ethmoid bone is open superiorly. The ethmoid roof itself is created by the frontal bone. Indentations or *foveolae* in the frontal bone cover the corresponding clefts and cells of the ethmoid.

Keros has described three different and surgically important types of configurations of the ethmoid roof. The differentiation depends on the length of the lateral lamella of the cribiform plate, (FIG 14) which is the thinnest bone in the entire anterior skull base. In type 1, the olfactory fossa is only 1 to 3 mm deep, the lateral lamella is short (almost nonexistent), and the ethmoid roof is almost in the same plane as the cribiform plate. In type 2, (FIG 14) the olfactory fossa is from 4 to 7 mm deep, and the lateral lamella is longer. In type 3, (FIG 14) the olfactory fossa is 8 to 16 mm deep, and the ethmoid roof lies significantly above the cribiform plate. Because of the danger that instrumentation can penetrate the thin and vulnerable lateral lamella, this is the configuration of greatest concern for the surgeon.

Controversy surrounds the terms *fovea* and *foveolae ethmoidales*. The anterior two thirds of the ethmoid complex opens superiorly, and the cells and clefts in this area are closed over by the frontal bone. Small pits or indentations overlie the open ethmoid clefts and spaces, which are open superiorly. These indentations are the *foveolae* (from the Latin, *foveolae ethmoidales ossis frontalis*, meaning ethmoid pits of the frontal bone). Use of the term *fovea* for the entire ethmoid roof does not distinguish between the endonasal view and the view from above looking down on the olfactory groove. While any individual pit may be called a *fovea* or *foveola,* the ethmoid roof may not. The Anatomic Terminology Group recommends that only the term *foveolae ethmoidales* (of the frontal bone) be used and advises that the terms *fovea* and dome of the ethmoid not be used. The clinical significance of the Keros classification accrues from the fact that the risk of intracranial entry during surgery increases with the length and, consequently, angulation of the lateral lamella of the cribiform plate. When a patient has a type 3 configuration, perhaps 14 to 16mm of anterior cranial fossa is medial to a place where instrumentation may be used.

Concha Bullosa.

When there is pneumatization of the middle turbinate, the term *concha bullosa* (FIG 28) is used. The term may also apply to pneumatization of the superior turbinate. The pneumatization of the middle turbinate usually originates from the frontal recess or the *agger nasi*, and growth of a *concha bullosa* may begin late in life.

The *concha bullosa* must be distinguished from an inter-lamellar cell , which arises from pneumatization of the vertical lamella of the middle turbinate from the superior meatus . The concha bullosa is a normal variant that in itself does not require surgery, but the presence of a concha bullosa may predispose a patient to occlusion of the ostiomeatal complex and subsequent sinus disease. Therefore, surgery may be appropriate.

Infraorbital Ethmoid Cell (Haller's Cell).

The potential pathophysiologic importance of a Haller' s cell (29,30) is clear, but the anatomic definition is not. As described by Haller in 1765, these cells grow into the bony orbital floor that constitutes the roof of the maxillary sinus, are differentiable from the bulla, and have a potential pathophysiologic relationship to a narrowed ethmoid infundibulum or maxillary sinus ostium.

The term *cellula orbitoethmoidalis* or orbito-ethmoid cell does not indicate, for example, that the cell grows directly into the floor of the orbit. The term infraorbital ethmoid cell is better because it implies contrast with a supraorbital cell that originates from the frontal or suprabullar recess. For exactitude, the full term is infraorbital cell of the anterior or posterior ethmoids, depending on its origin.

Ostiomeatal Complex.

No consensus exists to define exact anatomic descriptions of the borders and margins of the ostiomeatal complex. (FIG 30) Rather, the ostiomeatal complex is a functional entity of the anterior ethmoid complex that represents the final common pathway for drainage and ventilation of the frontal, maxillary, and anterior ethmoid cells. (FIG 7) Any or all cells, clefts, and ostia, with their dependent sinuses, may become diseased, thereby contributing to the symptoms and pathophysiology of sinusitis.

POSTERIOR ETHMOID AND RELATED STRUCTURES

Posterior Ethmoid and Sphenoid Sinus .

There are only a few terms in anatomic nomenclature that require a better definition and explanation in these regions.

Like the middle turbinate, the superior and, if present, supreme turbinates are attached to the lateral nasal wall and the anterior skull base by means of their basal lamellas. (FIG 3) The course of attachment of the supreme turbinate is similar to that of the middle turbinate but of less significance in pathophysiology and surgery. The superior nasal meatus (*meatus nasi superior*) and supreme nasal meatus (*meatus nasi supremus*) lie underneath the respective turbinates. Because the individual cells and clefts underneath the supreme (or fourth) turbinate are nowhere defined in the literature, they are considered part of a single posterior ethmoid complex.

The sphenoethmoid recess (*recessus sphenoethmoidalis*) is the space between the superior (and supreme, if present) turbinate laterally, the roof of the nose (*rima olfactoria*) superiorly, and the nasal septum medially.(FIG 35A) Its posterior border is the anterior face of the sphenoid bone. Medially there is no clear cut inferior border, and laterally the inferior border is seen at the inferior margin of the superior turbinate. The anterior extension is equally ill-defined, passing into the common nasal meatus.

Sphenoethmoid Cell.

Posterior ethmoid cells can become pneumatized far laterally and to some degree superiorly to the sphenoid sinus, in which case they are called sphenoethmoid cells (*cellulae sphenoethmoidales*) or Onodi cells. (FIG 36,37,38). Prominence of the optic nerve tubercle (optic nerve indentation into the sinus) or the internal carotid artery is not prerequisite, however. Yeoh *et.al*. has shown that in 15% of sphenoethmoid cells in Asians, the optic nerve is closely apposed to the wall of the sphenoethmoid cell without showing an indentation. Optic nerve indentation into the sinus air cells may be prominent in other posterior ethmoid cells as well. Whether ethmoid complex components grow posteriorly alongside the sphenoid sinus or sphenoethmoid cells pneumatize directly into the sphenoid bone has not been resolved, but the answer does not bear on practical issues in diagnosis and surgery: the air space in question is clearly ethmoid.

The optic nerve and carotid artery may be exposed in a sphenoethmoid (Onodi) cell. (FIG 38) This is clinically significant because the sphenoid sinus is located medially and inferiorly to the most posterior cell of the posterior ethmoid complex. Consequently, attempts to use instrumentation to locate the sphenoid sinus directly behind the last cell of the posterior ethmoid complex may result in serious damage to the optic nerve or carotid artery.

Pneumatization of the clinoid process in those cases may originate from the posterior ethmoid cell, also.

<u>Optic Nerve Tubercle (Optic Nerve Indentation into the Sinus Air Cell).</u>

The bulge of the medial aspect of the bone surrounding the optic foramen (*foramen opticum*) is the optic nerve tubercle (*tuberculum nervi optici*) . Depending on the degree of pneumatization and the presence and configuration of sphenoethmoid cells, it can be seen in the posterior ethmoid cells, at the transition between the posterior ethmoid and sphenoid sinuses, or in the sphenoid sinus itself. The optic canal (*canalis opticus*) can project into the sinus lumen, (FIG 46) and dehiscences of the bony wall may be present. The optic nerve may pass through a sphenoethmoid cell (FIG 38, 55) or sphenoid sinus (FIG 46, 53) like a column, surrounded by pneumatized space. There may be an infraoptic recess (FIG 38, 46, 49) between the optic nerve and the internal carotid artery. The more pronounced the pneumatization of the anterior clinoid process, the deeper the recess. (FIG 55)

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CHAPTER 5

DEFINITIONS OF RADIOLOGICAL ANATOMY USED IN THIS STUDY.

This study specifically focused on the frontal sinus, the presence of concha bullosa, Haller cells, the sphenoethmoid cell (Onodi) and the degree of pneumatization of the sphenoid sinus in relation to the carotid artery and optic nerve. The following is the definition of radiological anatomy used in this study. The defined anatomical landmarks are cross referenced to the illustrations of this thesis.

Frontal pneumatization pattern definitions and criteria

The frontal cells are divided into an anterior group (Types I to IV after Van Alyea), a posterior group (the suprabullar cell, the frontal bulla cell and the supra-orbital ethmoid cell) and a medial group (the interfrontal sinus septal cell). Sagittal plane CT views were not routinely available when the Anatomic Terminology Group made their recommendations in 1993 thus these terms were not included in the 1993 consensus statements. These frontal cells, however, have already been described by Van Alyea in 1941 through cadaveric dissection studies. Without sagittal CT views, it was impractical to describe these frontal cells as accurate diagnosis was not possible on coronal and axial views alone.

Frontal Recess Cell Description

Agger nasi cell (FIG 5)

Defined as the most anterior ethmoid cell, the first air cell seen when viewing a coronal CT scan from anterior to posterior and as a swelling along lateral nasal wall anterior to middle turbinate vertical attachment (endoscopic view). It is well seen on sagittal and coronal CT views.

Frontal cell, type 1 (FIG 8)

Defined as a single anterior ethmoid cell above the agger nasi cell. Its posterior wall is not the skull base but is a free partition in the frontal recess. It is well seen on coronal and sagittal CT views.

Frontal cell, type 2 (FIG 9)

Defined as a tier of 2 or more anterior ethmoid cells that pneumatize above the *agger nasi* cell. Its posterior wall is not skull base but is a free partition in the frontal recess. It is well seen on coronal and sagittal CT views.

Frontal cell, type 3 (FIG 10)

Defined as a single large anterior ethmoid cell above the agger nasi cell. It pneumatizes along inner aspect of the anterior frontal sinus table from the anterior frontal recess. It extends far into true frontal sinus. Its superior wall (cap) inserts upon the inner aspect of the anterior frontal sinus table (seen on sagittal CT image). Its posterior wall is not skull base but is a free partition in the frontal recess. It is well seen on coronal and sagittal CT views.

Frontal cell, type 4 (FIG 11)

Defined as an isolated cell within frontal sinus and above the *agger nasi* cell. It appears as an “air bubble ” on coronal CT scan. It appears as a “balloon on a string” on sagittal CT view. The anterior and inferior margin is the anterior frontal sinus table or frontal sinus floor. Its posterior boundary is a cell wall and not posterior frontal sinus table. Its identification requires both sagittal and coronal CT views.

Supraorbital ethmoid cell (FIG 12,46)

Defined as an ethmoid cell that extends over the orbit from the frontal recess. It may be single or multiple and may mimic the appearance of a septate frontal sinus. It opens into the lateral aspect of the frontal recess (This opening is lateral and posterior to the true frontal sinus ostium.). Its identification requires review of both axial and coronal CT views.

Frontal bulla cell (FIG 16)

Defined as an ethmoid cell above ethmoid bulla. It pneumatizes along skull base into frontal sinus from posterior frontal recess. Its posterior wall is anterior cranial fossa skull base (frontal sinus posterior table). Its anterior border must extend into frontal sinus. It is located behind the true frontal sinus pneumatization tract. It may represent pneumatization of the anterior wall of the ethmoidal bulla (*bulla lamella*). It may cause convexity in the floor of frontal sinus. It is well seen on sagittal CT view.

Suprabullar cell (FIG 21)

Defined as an ethmoid cell above ethmoid bulla. Its superior wall is anterior cranial fossa skull base. Its anterior border does not extend into frontal sinus. It may represent pneumatization of the anterior wall of the ethmoidal bulla (*bulla lamella*). It is well seen on sagittal CT view. It bears close resemblance to the suprabullar recess (CT view alone is inadequate to distinguish between the SBC and the suprabullar recess.)

Interfrontal sinus septal cell (FIG 22,24)

Defined as pneumatization of the frontal sinus septum. It drains into one frontal recess. It is associated with pneumatized *crista galli.*(FIG 25) It is well seen on axial and coronal sinus CT views.

Recessus terminalis (FIG 26)

Defined as present when the superior uncinate process attaches laterally to the orbit, below the internal frontal ostium. The frontal sinus drains directly into middle meatus. It is often associated with the *agger nasi* cell. It is well seen on coronal sinus CT view.

Anterior and Posterior Ethmoid Arteries (FIG 13,15,46)

Defined as present when a protrusion is noted at the superior lateral aspect of the orbit extending medially. It is seen on coronal sinus CT view as a medial protrusion from the superior medial aspect of the orbit.

Concha Bullosa (FIG 28)

Defined as extensive pneumatization of the middle turbinate. In this study, any degree of pneumatization was considered significant and recorded to show presence of a concha bullosa. It is seen on coronal and axial sinus CT views.

Haller Cell (FIG 29)

Defined as present when a pneumatized air cell is seen at the inferior medial aspect of the orbit forming the superior roof of the ostium of the maxillary sinus. The lateral boundary of the cell is the inferior medial aspect of the floor of the orbit. It is seen on coronal and axial sinus CT views.

Sphenoethmoid Cell.(FIG 36)

Defined as present when a posterior ethmoid cell is seen extending posteriorly over the anterior wall of the sphenoid sinus. This cell may or may not contain the Optic Nerve. It is seen on sagittal sinus CT view.

Cells derived from the ethmoid lying within the sphenoid bone were referred to as Onodi cells (named after the Hungarian surgeon) by Lang . This definition, however, differs from that adopted by Kainz and Stammberger who categorized the Onodi cell as a posterior ethmoidal cell presenting with an optic nerve canal bulge. The author has adopted Onodi's original description which is consistent with Onodi's work which was an anatomical study whereas Kainz and Stammberger were working from endoscopic sinus surgeon's views.

<u>Extent of Pneumatization of the Optic Nerve Within the Sphenoethmoid cell</u>

The degree of pneumatization in the vicinity of the optic nerve within the sphenoethmoid cell is categorized into 5 separate types in this study.

Type 0 represent no adjacent pneumatization
Type 1 represent pneumatization adjacent to optic nerve
Type 2 represent pneumatization adjacent to optic nerve with sphenoid indentation
Type 3 represent pneumatization of less than 50 % of circumference of optic nerve
Type 4 represent pneumatization of more than 50% of circumference of optic nerve (FIG 55)

This is best seen and interpreted on the coronal and axial CT sections.

<u>Sphenoid Pneumatization</u>

The conchal type is characterized by the presence of solid bone below the sella without any pneumatization.(FIG 40)

In the presellar type, pneumatization is limited to the region anterior to the plane that is parallel to the anterior sellar wall. (FIG 41)

In the sellar type, the pneumatization extends beyond the anterior wall but does not penetrate past the posterior sellar wall. (FIG 42)

In the postsellar variation, the pneumatization extends beyond the posterior wall of the sella. (FIG 43,44)

These are seen on sagittal sinus CT view.

Extent of Pneumatization of the Internal Carotid Artery in the Sphenoid Sinus.

Based on the on the extent of sphenoid pneumatization around the retrosellar segment of the Internal Carotid Artery.

Categorized based on the degree of exposure within the sphenoid sinus.

Type 0, represent no exposure (FIG 47)
Type 1, represent exposure of < 90 degrees (FIG 48)
Type 2, represent exposure of >90 but <180 degrees
Type 3, represent exposure of >180 degrees, (FIG 49)

This is seen on Axial Sinus CT view : based upon the relationship between the postsellar Internal Carotid Artery and the adjacent sphenoid pneumatization.

Extent of pneumatization around Optic Nerve within the sphenoid sinus.

The degree of pneumatization in the vicinity of optic nerve is categorized into 5 separate types in this study.

Type 0 represent no adjacent pneumatization (FIG 51)
Type 1 represent pneumatization adjacent to optic nerve
Type 2 represent pneumatization adjacent to optic nerve with sphenoid indentation (FIG 52)
Type 3 represent pneumatization of less than 50 % of circumference of optic nerve (FIG 53)
Type 4 represent pneumatization of more than 50% of circumference of optic nerve (FIG 54)

Seen on Coronal and Axial Sinus CT views.

Discussion on System of Defining Pneumatization of the Optic Nerve and Internal Carotid Artery in the Sphenoid Sinus.

The systems of definition were chosen so that a comparison could be made with previous published articles. These articles although written by the same authors were separate papers written for the Optic Nerve and Internal Carotid Artery and did not adopt a standard system describing the pneumatization of these structures in the sphenoid sinus.

Type 0 and 1 of Optic Nerve pneumatization actually corresponds to Type 0 of Internal Carotid Artery pneumatization. Type 1 of Optic Nerve pneumatization has been added into the system as it is an important entity to recognize during endoscopic sinus surgery. Yeo *et. al.* had shown in their series that 15% of sphenoethmoid cells showed no optic indentation but the adjacent bone was only 0.25mm thick. These are the Type I pneumatization types described in this thesis. Type 0 Optic Nerve pneumatization would mean that the optic nerve is well protected by intervening bone and is unlikely to suffer injury during surgery.

The Internal Carotid Artery being a structure at the inferior aspect of the sphenoid sinus is actually less likely to be injured at surgery as the sphenoid sinus is usually approached on its superior anterior face. It was also found in the study that the Internal Carotid Artery being a bigger structure than the Optic Nerve was either well protected by thick bone, or when adjacent to the sphenoid sinus, tended to show an Internal Carotid Artery bulge. Types 2, 3, and 4 of Optic Nerve pneumatization corresponds with Types 1, 2 and 3 of Internal Carotid Artery pneumatization.

Sphenoid Septal Variations and Attachments.

The presence of the central and accessory septa of the sphenoid sinus is noted. The variation in attachments of these septae to the optic nerve and the internal carotid artery is noted. This is seen on axial sinus CT view. (FIG 50)

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CHAPTER SIX

TRIPLANAR COMPUTED TOMOGRAPHY & SURGICAL NAVIGATION

The technology used in this study is derived from Surgical Navigation protocols supporting endoscopic sinus surgery which enable CT views to be interpreted with greater accuracy as each interpretation is supported by simultaneous views in the coronal, axial and sagittal planes. Previous reports of paranasal sinus anatomy were based on coronal plane CT views alone and some of this data may need to be reviewed for accuracy in view of the limitation of a single coronal plane of interpretation. Paranasal sinus anatomy studies based on tri-planar CT projection have only been recently published in the otolaryngology literature in 2004.

The following is an edited monologue on the subject of Surgical Navigation submitted by this author and co-author Martin Citardi MD for publication as a chapter entitled: “Image Guidance in Endoscopic Sinus Surgery” for a book entitled “Otolaryngology : A Surgical Notebook” edited by K.J. Lee and E. Toh for Thieme Medical Publishers. Publication is pending. Understanding the principles and technology underlying surgical navigation explains the process of pre-operative evaluation upon which this study is based and of the illustrations used to aid understanding of paranasal anatomy in this thesis.

Defining Surgical Navigation.

In 1996, the International Society for Computer-Aided Surgery proposed:

"The scope of computer-aided surgery [CAS] encompasses all fields within surgery, as well as biomedical imaging and instrumentation, and digital technology employed as adjunct to imaging in diagnosis, therapeutics and surgery. Topics featured include frameless as well as conventional stereotactic procedures, surgery-guided by ultrasound, image-guided focal irradiation, robotic surgery and other therapeutic interventions that are performed with the use digital imaging technology".

The term "image-guided surgery" (IGS) has been used to describe the specific CAS application of intraoperative surgical navigation.

Defining Image Guidance Surgery

A computer-based system to track the position of an instrument tip which is projected as a virtual point in cross hairs on to a pre-operative CT scan rendered in triple orthogonal projections (coronal, axial, sagittal) simultaneously. It includes the preoperative and intraoperative review of preoperative CT scans at the computer workstation.

Role of IGS in Sinus Surgery

Conventionally, the surgeon relies on his or her memory and interpretation of pre-operative coronal CT scans of the paranasal sinuses as a guide during endoscopic sinus surgery. With IGS, the preoperative CT scans in the coronal, axial and sagittal planes are projected on a computer monitor during surgery, and the position of the instrument tip which is tracked dynamically, is shown relative to preoperative CT scans. In effect, IGS facilitates preoperative surgical planning by providing a better CT scan "road map" as it provides three simultaneous orthogonal planes for interpretation instead of the conventional single coronal CT scan view. The surgeon may directly relate the surgical anatomy of the preoperative sinus CT with the intraoperative anatomy of the surgical field

How Image Guidance Works

The IGS computer tracks the movement of a mathematically designated virtual point in space relative to a frame of reference via electromagnetic sensors or a camera array that detects infrared light. The tip of the instrument is not directly tracked, but its constant geometric position relative to the tracking instrumentation attached to the instrument is used to project the virtual point on the computer monitor. The computer system displays both the preoperative sinus CT and the virtual point relative to the same reference frame, thus allowing the surgeon to interpret where the virtual point is in relation to the patient's sinuses.

It should be noted that this reference frame may be a rigid physical structure (as in traditional framed stereotaxy) or a virtual frame composed of fiducial points (as in most sinus surgery applications).

Differences in Tracking Systems

There are two types of tracking systems namely the electromagnetic system and the optical system.

Electromagnetic systems work by detection of movement of a sensor within an electromagnetic field. The main advantage of this system is that there are no line of sight problems in which instruments such as the endoscopic camera head can obstruct the sensing probe from an overhead camera array. The disadvantage of this system is that ferromagnetic objects (including most surgical instruments and devices) can disturb the accuracy of tracking if too many metallic objects are brought within the sensing field. There is presently only one commercial system available in Singapore : General Electric Medical Systems Navigation & Visualization (Waukesha, Wisconsin, USA) InstaTrak and ENTrak. Medtronic has launched its EM system in the United States at end 2005.

Optical systems work by detection of movement of a infra-red emitter or reflector by an overhead infrared camera array. The advantages of this system include tracking not being influenced by magnetic objects and when system is actively tracking, tracking error is sub-millimetric. The disadvantage of this system is that of a line of sight problem. The surgeon must maintain line of sight between the camera array and infrared emitter/reflector on the surgical instrument and he has to make this adjustment intra-operatively whenever he requires tracking.

Several systems are available commercially : BrainLab (Heimstetten, Germany) Vector Vision and Kolibri ,Medtronic Xomed (Jacksonville, Florida USA) LandMarX and StealthStation, Stryker Corporation (Kalamazoo, Michigan USA) Navigation System.

Essential Technical Terms

Terms Related to the Pre-operative CT and Tracking

Calibration: Process of establishing or confirming the relationship between a tracker and the tip of an instrument.

CT Scan Volume: The virtual volume imaged by the preoperative CT scan. (Each point in this volume also has a unique xyz coordinate.)

Dynamic reference frame: A tracker attached to the patient which serves as the reference for all localizations.

Operative Field Volume: The space around the surgical site in which tracking occurs. (Each point in this volume has a unique xyz coordinate.)

Tracker: Any device which may be used to monitor a virtual point within the operating field volume.

Image Registration

As the paranasal sinuses are relatively rigid, rigid-body transformations are used to accomplish image registration. Point-based registration is used to determine transformation and fiducial markers are used to establish accurate fiducial points for registration, the points being established by a set fiducial localization process. Accuracy is important to these systems as is knowledge of the level of accuracy. Bone implanted markers are of course the best as registration error depends only on the fiducial localization error (FLE) and is thus to a large extent independent of the particular object being registered.

Terms Related to Registration

Fiducial Points: Corresponding reference points (each with a unique xyz coordinate) in the CT scan volume and operative field volume which are aligned for registration. In less technical jargon, reference points on the patient upon which the pre-operative CT scan is superimposed.

Registration: Process of aligning corresponding xyz coordinate points in the operative field volume and CT scan image volume

Terms Related to Accuracy

Fiducial Registration Error (FRE): Mathematically derived value that expresses the closeness of the fit of each fiducial point to the entire registration. Rigid-body point-based registration is achieved by finding the rigid transformation that minimizes FRE which is the root mean square distance between homologous fiducials after registration.

Root Mean Square (RMS): Refers to the mathematical model used to derive FRE.

Surgical Navigation Error: An estimate of the distance between the true xyz coordinate and the indicated xyz localization provided by the navigation system. Surgical navigation error is functionally equivalent to target registration error. (For clinical systems, surgical navigation error may only be determined through a visual estimation by the surgeon.)

Target Registration Error (TRE): Estimate of the error between a known point in the operating field volume and the indicated localization provided by the IGS system. It is the distance between homologous points other than the centroids of fiducials. TRE answers the question "How close to target?" Expected registration accuracy which is represented by TRE is worse near the fiducials that are most closely aligned. Fiducial alignment should therefore not be relied upon as an indicator of the accuracy of point-based guidance systems. TRE is the technical term for surgical navigation error.

Registration Protocols

Paired Point Registration

Bone anchored fiducial markers are most accurate but involves putting a screw into the skull, an impractical option in routine sinus surgery. Surface fiducial markers are pasted on the patient's skin before pre-operative CT. Such fiducials may shift due to relative movement of the skin and require the CT to be done very shortly before operation.

For paired point registration without use of markers, anatomic fiducial points such as the tragus, medial and lateral canthus of the eye, the ala and the columnella of the nose must be registered just prior to start of surgery. In general, paired-point registration is considered time-consuming.

Automatic Registration

Specially designed headsets contain fiducial markers and are worn during pre-operative CT scanning. The same headset is then worn intra-operatively. The headset is designed so that its placement on the patient's head is reproducible; thus the relationship between the fiducial markers and the patient's anatomy is deemed fixed. The computer software processes the preoperative CT data and localizes the fiducial markers automatically. Automatic registration is considered fast and efficient; however, appropriate headset placement during the preoperative CT scan and during surgery is critical.

Contour-based Registration

The surface contour of the patient's face can be registered by applying a laser whose reflections upon the surface is collected by the overhead camera array (also known as a digitizer). Alternatively, multiple physical localizations with a tracking probe may define a contour for registration.

Comment on Registration Protocol and Tracking System

Although automatic, headset-based registration is associated with electromagnetic tracking, and paired point registration is associated with optical tracking, the specifics of registration are independent of the tracking technology. In theory, paired-point registration and automatic registration may be used with optical or electromagnetic tracking; however, each commercially available IGS system relies upon a single tracking technology (optical or electromagnetic) and has been optimized by its engineers for a specific registration protocol (paired-point, automatic and/or contour-based).

Obviously laser-based registration requires an optical digitizer. Furthermore, contour-based registration may be theoretically integrated for any type of tracking technology.

Surgical Navigation Error

RMS or FRE values do not represent the accuracy of surgical navigation.

TRE is the true representation of the accuracy of surgical navigation. Clinically, TRE is the surgeon's estimate of the closeness of IGS-generated localizations against known anatomic landmarks.

Intra-operative visual estimates are essential for checking system accuracy and should be repeated multiple times as DRF may shift during surgery.

Apparent TRE estimates may vary in different parts of the operating field volume. For instance, the IGS system may seem quite accurate in the anterior ethmoid system, but much less accurate in the sphenoid. Assessing TRE at the tip of the nose or on the surface of the cheek is thus not optimal. Such assessments should occur as close to the actual surgery sites as possible.

Components of Image Guidance Systems.

The computer workstation interprets the mathematical spatial model of tracking which is projected onto a display system (LCD or CRT monitor). The tracking system feeds information of movement of surgical instruments that are tracked to the computer workstation. In most systems, the tracking system also monitors the position of the surgical field. Data transfer hardware is required to transfer the preoperative CT scans into the computer workstation in the operating room. Such hardware may be a network system connection as well as magnetic or optical disk drives. Most commonly, data transfer of preoperative CT scan image data utilizes the DICOM standard. Integrating software allows for manipulation of CT images (such as window width and level adjustments for bone and soft tissue windows). Software may also allow coloring of a specific anatomic region such as the orbit and projecting the colored orbit in the display system during intra operative surgical navigation for better identification. On some systems, virtual endoscopy much like virtual colonoscopy may also be performed by software manipulation pre- and intra-operatively.

Uses of an Image Guidance in Surgery

IGS is an enabling technology and not a substitute for surgical expertise. Throughout IG-FESS procedures, the principles of mucosal preservation and mucociliary clearance should be strictly adhered to (as outlined by Kennedy).

IGS incorporates both preoperative planning and intraoperative surgical navigation.

Pre-Operative Planning

Simultaneous viewing of a single point in triple orthogonal projections (i.e. coronal, axial and sagittal views) allow pre-operative interpretation not achievable by viewing conventional coronal CT sections alone. For example, in endoscopic frontal sinusotomy, the sagittal view on CT facilitates surgical planning for the resection of the posterior leaf of an anteriorly based frontal recess cell (such as an agger nasi cell) and/or the anterior leaf of a posteriorly based frontal recess cell (such as the suprabullar cell).

Intra – Operative Surgical Navigation.

Although it is possible to track surgical instruments (curettes and even microdebriders) continuously throughout surgery, this is seldom necessary in real surgical practice.

IGS is certainly useful in important anatomic regions such as the frontal recess, when important anatomic landmarks are absent such as in revision cases and in intra-operative confirmation of the following important landmarks : the skull base, the anterior ethmoidal artery, the nasolacrimal duct during uncinectomy, the site of transethmoid entry into the sphenoid sinus and the optic nerve in a sphenoethmoidal cell.

In endoscopic surgery outside the paranasal sinuses, it is especially useful in confirming the position and thus avoiding injury to the carotid artery, the basilar artery and the brainstem in skull base surgery.(FIG 45)

Details of the IGS Process.

CT scan is completed with the specific scan protocol required by the system. Ideally, the CT slice thickness is as thin as possible. For headset-based registration, the headset must be placed on the patient before scanning,

Data from this CT scan is transferred to the IGS computer workstation via computer network or disk. The surgeon reviews the CT scan pre-operatively.

After induction of anesthesia, registration is performed in accordance with the protocol required by the IGS system. A visual estimate of surgical navigation accuracy is performed. Some systems require the designation of a so-called “verification point” for this purpose.

Surgical navigation accuracy (also known as TRE) must be monitored throughout the procedure. Verify to a known anatomical landmark as mentioned below whenever the IGS is to be used to confirm an uncertain anatomical position.

Appropriate anatomical landmarks for assessing TRE include the anterior aspect of the nasal septum, the anterior inferior aspect of the middle turbinate, the posterior aspect of the nasal septum, the floor of the sphenoid sinus, the anterior wall of the sphenoid sinus, the posterior wall of the maxillary sinus and the medial orbital wall/ *lamina papyricea.*

Shrinkage of nasal mucosa from vasoconstrictive agents applied may influence the position of the virtual point in relation to intra-nasal soft tissue. For example, the mucosa of the inferior turbinate seen on a pre-operative CT scan may not correlate accurately on IGS after vasoconstriction. Bony partitions will not be affected by vasoconstriction.

The DRF (headset) may be inadvertently moved due to manipulation during the operation. The resultant TRE will only be evident if constant verification is performed as mentioned above.

For electromagnetic systems, metallic objects into the surgical field will increase TRE. For optical systems, it is essential to allow the overhead camera to see the trackers. The camera head of the endoscope may at times block this line of sight for the overhead camera.

It is important to note that structures removed during the operation are not reflected on the pre-operative CT scan that is projected in the display system.

At the end of the operation, the DRF (headset) is removed, and the pre-operative CT information of the patient remains within the computer workstation. This stored CT information may be reviewed at a later date.

Limitations of IGS.

The CT scan projected at surgery is a pre-operative CT scan and not a real time CT view. Removal of tissue during surgery is not reflected on this pre-operative scan. The accuracy of the system is dependent on the slice thickness of the preoperative CT. The best CT slice thickness is presently 1mm in most centers. The accuracy of surgical navigation is affected by the distance of the localization from the Centroid (point that is equidistant from all fiducial points). Thus, in most instances, TRE is lower in the anterior ethmoid than in the sphenoid. The position of the DRF may shift due to manipulation during surgery affecting surgical navigation accuracy.

Current and Future Status

It is widely accepted that IGS is an excellent enabling tool in endoscopic sinus surgery.

Better understanding of paranasal sinus anatomy using simultaneous triple orthogonal CT projections influences surgical planning and execution and has the potential to give better post-operative results in experienced surgical hands.

IGS may in time become as essential to future endoscopic sinus surgery endeavors as the coronal CT is to current practice.

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CHAPTER 7

MATERIALS AND METHOD

Fifty pre-operative CT scans with Image Guidance Protocol producing Tri-planar Orthogonal Projections were studied. This yielded one hundred sinus sides for study. The majority of these patients had sinusitis and nasal polyposis affecting the anterior sinuses with two patients with mucoceles and one with an encephalocele.

The following criteria were also applied in the selection of CT scans for analysis : that no previous sinus surgery had been performed and that soft tissue disease was not gross enough to obscure the configuration of air cells, especially the frontal air cells.

The patients were Asian adults (80%Chinese, 8% Malays, 8% Indians and 4% Others) with an Age Range of 21 to 77 years. The Mean Age was 45.9 years with a Standard Deviation of 14.9 years. Median Age is 46.5 years. Gender ratio was 36 males to 14 females. Ethnicity was determined from the stated race on the patients' national registration identity card. The patients' ethnic backgrounds in absolute numbers and as a percentage compared to Singapore racial demographics were 40 Chinese (80% in this study cf. 76% Singapore Racial Demographics), 4 Malays (8% cf. 13%) , 4 Indians (8% cf. 8%) and 2 Others (4% cf. 3%). The preponderance of Chinese patients reflected the racial cohort of Singapore and patient mix of Tan Tock Seng Hospital. The patients were thus predominantly Chinese (of southern origin) and dilution of Chinese ethnicity by intermarriage with other races was not a significant issue. They underwent CT scans in the period from June 2002 to April 2005 in preparation for Image Guided Endoscopic Sinus Surgery.

CT scans were performed on a Toshiba Aquillion Multislice CT System with the following radiological protocol : Slice thickness of 2mm with table movement of 0.8mm at a field view of 220mm with scan being inclusive of all markers on the headset. The CT scans were read on an Instatrak 3500 Connectstat Workstation using UNIX based propriety software from Visualization Technologies, Inc. (VTI of Lawrence , Mass, USA). Transfer of data was via Magnetic Optical Disks to the Hard Disk Drive of the Workstation. The Workstation allowed simultaneous viewing of a specific point of reference in three views, the coronal, axial and sagittal views and capturing of images in JPEG format used in the Illustrations section. The images were downloaded on 1.44 in. floppy disks for transfer.

The anatomical structures of interest were identified and scored for each sinus by the author and the prevalence of each anatomical feature tabulated.

Illustrations also include images captured during surgery with the Instatrak 3500 Image Guidance System at Tan Tock Seng Hospital and photographs taken of sagittal cadaveric dissection specimens in the Experimental Laboratory , Singapore General Hospital during the 8th and 10th Annual Endoscopic Sinus Surgery Course in 2003 and 2005. Photographs were shot with a Sony DSC 707 camera at 3 megapixels, f5.6, 1/125, Macro setting.

The images were edited with Adobe Photoshop version 7.0 to remove identification cues such as patient's names and to draw the arrows used to lead the reader's attention to specific anatomical features.

NO	NAMES	SEX	AGE	RACE	NRIC	SCAN DATE
1	AYH	M	61	Chinese	S2137953J	02.09.2004
2	AYWW	M	22	Chinese	S8304020C	04.11.2004
3	AZJ	M	41	Malay	S1639586B	27.04.2005
4	CSF	M	55	Chinese	S0047979I	11.05.2005
5	EGK	M	64	Chinese	S0925438B	14.04.2005
6	FSU	M	74	Chinese	X3042492A	25.04.2005
7	GSS	M	42	Indian	S2718805B	18.12.2003
8	GLY	F	35	Chinese	S7085795B	03.07.2003
9	HWD	M	23	Chinese	S8136455I	30.10.2003
10	HSM	M	56	Chinese	S0960611D	06.11.2002
11	HSL	F	37	Chinese	S6807417G	25.08.2003
12	KK	M	27	Chinese	G7069989M	18.12.2003
13	KSK	F	55	Chinese	S0032653D	13.01.2005
14	LCH	F	50	Chinese	S1117460D	12.06.2002
15	LYS	M	51	Chinese	S0166916H	26.08.2004
16	LBL	F	47	Chinese	S1137041I	30.10.2003
17	LBP	M	64	Chinese	S0858228I	29.04.2004
18	LJWJ	M	21	Chinese	S8413098B	08.04.2004
19	LYQ	F	19	Chinese	S8514178C	14.03.2003
20	LBH	M	40	Chinese	S2596208A	13.05.2003
21	LAC	F	47	Chinese	S1319547A	12.06.2002
22	LKE	F	77	Chinese	S1386651A	25.03.2004
23	LD	M	54	Chinese	S0094481E	25.04.2005
24	LHX	M	68	Chinese	G5580113X	21.08.2002
25	M	F	40	Chinese	S1715498B	20.11.2002
26	MIMSH	M	37	Malay	F5612110l	03.07.2003
27	MT	M	69	Malay	F0662584M	05.08.2002
28	MMLB	M	30	Others	F7852746M	05.01.2005
29	NKH	M	67	Chinese	S1063235H	14.02.2005
30	NAH	M	53	Chinese	S0051661I	04.07.2003
31	NBY	F	38	Chinese	S1829396Z	03.06.2003
32	NKY	M	73	Chinese	S0929226H	28.08.2002
33	NWL	F	27	Chinese	S7837328H	10.03.2005
34	OKT	M	48	Chinese	S1245284E	11.09.2003
35	OKB	M	40	Chinese	S1688877Z	13.02.2003
36	OWK	M	21	Chinese	S8424501A	04.11.2004
37	OKC	M	53	Chinese	S2015439Z	08.01.2004
38	PAK	M	48	Chinese	S1270433Z	04.11.2004
39	PCN	M	46	Chinese	S1362470D	18.03.2004
40	PCS	M	59	Chinese	S0531872F	04.09.2002
41	PNP	F	42	Indian	S1609667I	19.06.2003
42	RM	M	30	Indian	F8323099K	23.01.2003
43	RSR	M	42	others	F7599442G	01.04.2004
44	SWJ	M	24	Chinese	S8104293D	06.11.2002
45	SZ	F	45	Malay	S1444977I	29.04.2004
46	SC	F	42	Chinese	S1579913G	27.10.2004
47	SCY	F	49	Chinese	S1219808F	06.03.2003
48	STL	M	48	Chinese	S1279156I	25.09.2003
49	SR	M	42	Indian	S8301650G	01.04.2004
50	TAS	M	56	Chinese	S0217949J	11.12.2002

Table shows Patients entered into this Study.

CHAPTER 8

PRESENTATION OF DATA.

Definitions of Anatomical Structures and Study Methodologies.

Reports on the prevalence of anatomical structures in the paranasal sinuses can often differ significantly. Analysis of such discrepancies show that different methodologies used in studies and the definitions of the anatomical structures studied can produce significantly differing reports.

In anatomic dissection, the prevalence of the *agger nasi* cell has been reported as 10% to15% by Messerklinger, 40% by Mosher, 65% by Davis and 89% by Van Alyea. In investigations using coronal plane CT views , the prevalence of the *agger nasi* cell has been reported as 99% by Kennedy and Zeinrich and 98.5% by Bolger. Van Alyea commented in his studies that the *agger nasi* cell was often small and difficult to detect during anatomic dissection. It could thus be easily overlooked if not specifically looked for. CT scans demonstrate the *agger nasi* cell well even when the cell is small. Thus studies using CT scan views report a far higher incidence of the *agger nasi* cell as compared to reports derived from cadaveric dissection.

A difference in definition of the anatomical structure studied leads to different prevalence reports. Pratt and Pratt described the *agger nasi* as a prominence just above and anterior to the attachment of the middle turbinate. Mosher described the *agger nasi* as an air cell near the extreme anterior superior end of the middle turbinate with its inner boundary being the uncinate process and its outer boundary being the inner surface of the ascending process of the superior maxilla. Van Alyea described the *agger nasi* as originating from the uppermost anterior aspect of the infundibulum. Ritter described the cell with respect to the lacrimal bone, indicating that the *agger nasi* cell is the most anterior of the ethmoid air cells. Zinreich, with input from endoscopic sinus surgeons and coronal plane CT views proposed that the *agger nasi* cell is the air chamber below the frontal sinus which extends to the frontal sinus superiorly, reaches the lacrimal fossa inferolaterally and is anterolaterally arched by the nasal bones.

Although coronal plane CT views can demonstrate *agger nasi* cells much better than anatomic dissection, coronal plane CT views alone are inadequate in the study of frontal recess and sphenoethmoid cells. Tri-planar CT views, which are standard CT views in Image Guided Surgery allow paranasal sinus anatomy to be interpreted more accurately. It is only recently that this technology has been used to study paranasal sinus anatomy. The papers used to compare the prevalence rates of this study were all published in 2004.

Driben *et al* reported on the reliability of computerized tomography (CT) in detecting the sphenoethmoid (Onodi) cell in comparison with endoscopic dissection. A total of 41 sinonasal complexes from 21 human adult cadaveric heads were studied with standard coronal and axial plane CT views followed by subsequent endoscopic dissection. In his study, the prevalence of the sphenoethmoid (Onodi) cell as determined by CT views was 3/41 (7%) of the sphenoethmoid complexes. However, anatomic dissection identified a sphenoethmoid (Onodi) cell in 16/41 (39%) complexes. He concluded that coronal and axial CT viewing protocols for the paranasal sinuses did not reliably detect the Onodi cell. Endoscopic dissection indicated that the sphenoethmoid (Onodi) cell was a more frequent anatomic variant than previously appreciated. The sagittal component of this tri-planar CT view study clearly show posterior lateral pneumatization of a posterior ethmoid cell over the sphenoid sinus (FIG 36) and reduces error of identification of a sphenoethmoid cell.

The sagittal section also prevents identifying a sphenoethmoid cell in the coronal plane when there is actually none. (FIG 39)

In this study, the definitions of anatomical structures follow the consensus statements made by the Anatomic Terminology Group at the International Conference on Sinus Disease: Terminology, Staging, and Therapy, held in the United States in Princeton, New Jersey, in July 1993.

With regards to frontal sinus cells, the pneumatization of the optic nerve in the sphenoid sinus and the sphenoethmoid cell and the pneumatization of the internal carotid artery in the sphenoid sinus, the author has used the definitions proposed in the papers of Lee *et. al*. and Batra *et.al*. (2004) so that a meaningful comparative study can be made.

<u>Prevalence of Frontal Sinus Cells.</u>

TABLE 1

The *agger nasi* cell was found in the majority of sides studied (92%) consistent with previous reports using coronal plane CT (98%) and the report of Lee *et al*.(89%) . It was particularly important to identify the *agger nasi* as the definition of the four types of frontal sinus cells is based on the relationship of these cells to the *agger nasi*. When the roof of the *agger nasi* cell forms the anterior floor of the frontal sinus, anteriorly based frontal sinus cells do not exist. The prevalence of the types of frontal sinus cells (Type I : 40%, Type II : 15%, Type III : 12% , Type IV : 0%) were fairly similar to report of Lee et al. There is a similar high incidence of supra-orbital ethmoid cells (73% in this study compared to 62% in Lee's study) in both series.

There appears to be a higher prevalence of frontal bulla cells in this series (16% vs. 9%). The frontal bulla cell is an air cell that arises from above the ethmoid bulla and extends to the posterior aspect of the frontal recess. Its clinical significance is that it can cause narrowing of the frontal recess from posteriorly and when the indication arises, its anterior leaf has to be resected to allow good posterior drainage of the frontal sinus. It is difficult to identify based on coronal plane CT view alone.

The prevalence of supra-bullar cells (11%), inter-frontal sinus septal cell (19%) and the presence of a *recessus terminalis* (25%) is about similar to the comparative study.

PREVALENCE OF FRONTAL SINUS CELLS		
	RESULTS OF STUDY %	LEE, et al.[1]. %
AGGER NASI	92	89
FRONTAL CELL TYPE 1	40	37
FRONTAL CELL TYPE 2	15	19
FRONTAL CELL TYPE 3	12	8
FRONTAL CELL TYPE 4	0	0
SUPRAORBITAL ETHMOID CELL	73	62
SUPRABULLAR CELL	11	15
FRONTAL BULLA CELL	16	9
INTER FRONTAL SEPTAL CELL	19	14
RECESSUS TERMINALIS	25	22

TABLE 1

REFERENCE

1. Lee, W. T., F. A. Kuhn, et al. (2004). "3D computed tomographic analysis of frontal recess anatomy in patients without frontal sinusitis." Otolaryngol Head Neck Surg 131(3): 164-73.

Prevalence of Anatomic Variations.

TABLE 2

The higher prevalence of the sphenoethmoid cell in Asians (Chinese, Malays, Indians, Thais) is supported by the findings in this study. (55% vs. 65% and 60%Asians vs. 28.1% non Asians). The presence of Haller cells (37%) and Concha Bullosa (41%) were similar to the comparative study.

PREVALENCE OF ANATOMIC VARIATIONS			
	RESULTS OF STUDY (%)	COMPARATIVE STUDIES ASIAN (%)	COMPARATIVE STUDIES NON ASIAN (%)
SPHENOETHMOID CELL / ONODI	55	65 [1] 60 [2]	28.1[3]
HALLER CELLS	37	-	45.1[4]
CONCHA BULLOSA	41	-	53 [4]

TABLE 2

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4. Bolger, W. E., C. A. Butzin, et al. (1991). "Paranasal sinus bony anatomic variations and mucosal abnormalities: CT analysis for endoscopic sinus surgery." Laryngoscope 101(1 Pt 1): 56-64.

Relationship of the Optic Nerve to Sphenoethmoid Cell.
TABLE 3

The sphenoethmoid cell is defined as present when a posterior ethmoid cell is seen extending posteriorly over the anterior wall of the sphenoid sinus. This cell may or may not contain the optic nerve. This was described by Lang. This definition differs from that adopted by Kainz and Stammberger who categorized the Onodi cell as a posterior ethmoidal cell presenting with a optic nerve canal bulge. Based on Lang's definition, the optic canal bulge is seen in 48% of cases in this series with no optic bulge seen in 52% of cases. There is a higher incidence of optic canal bulge in the sphenoethmoid cell in this series in relation to the comparative study. (48% vs. 36.1%).

RELATIONSHIP OF OPTIC NERVE TO SPHENOETHMOID CELLS		
	RESULTS OF STUDY %	BATRA et al [1] %
0 NOT ADJACENT	2	5.6
1 ADJACENT	50	58.3
2 INDENTATION	38	25
3 < 50% EXPOSURE	4	2.8
4 >50% EXPOSURE	6	8.3
SEPTAL INSERTION ON OPTIC NERVE	0	-
DEHISCENT OPTIC NERVE	6	-

TABLE 3

REFERENCES

1. Batra, P. S., M. J. Citardi, et al. (2004). "Software-enabled CT analysis of optic nerve position and paranasal sinus pneumatization patterns." Otolaryngol Head Neck Surg 131(6): 940-5

Types of Sphenoid Sinus
TABLE 4

There were no conchal type of sphenoid sinus encountered in this series of adult sinuses. The majority of sinuses were of the postsellar type (78%) with fewer sellar (15%) and pre-sellar (7%) types.

TYPES OF SPHENOID SINUS		
	RESULTS OF THIS STUDY %	BATRA, et al [1] %
CONCHAL	0	4.7
PRESELLAR	7	4.7
SELLAR	15	25
POSTSELLAR	78	65

TABLE 4

REFERENCE

1. Batra, P. S., M. J. Citardi, et al. (2004). "Software-enabled computed tomography analysis of the carotid artery and sphenoid sinus pneumatization patterns." Am J Rhinol **18**(4): 203-8.

Carotid Artery Exposure in the Sphenoid Sinus
TABLE 5

There were no dehiscent carotid arteries seen radiologically in the sphenoid sinus encountered in this study series although the comparative study reported a 19.5% incidence. It is possible that the CT scan windowing chosen for reviewing the CT scans may have been different in the two studies thus yielding such a significant difference. In the majority of cases radiologic carotid exposure was about 90 to 180 degrees (58%) and less than 90 degrees (31%) . Exposure of more than 180 degrees was uncommon (3%). The carotid artery was safely tucked entirely in thick bone without exposure into the sphenoid in 8% of cases. There was a high incidence of septal insertion onto the carotid artery.(50%).

CAROTID ARTERY EXPOSURE IN THE SPHENOID SINUS		
	RESULTS OF THIS STUDY %	BATRA et al [1] %
0 NO EXPOSURE	8	12.5
<90	31	32.8
90-180	58	50
>180	3	4.7
SEPTAL INSERTION	50	37.5
DEHISCENT CAROTID ARTERY	0	19.5

TABLE 5

REFERENCE

1. Batra, P. S., M. J. Citardi, et al. (2004). "Software-enabled computed tomography analysis of the carotid artery and sphenoid sinus pneumatization patterns." Am J Rhinol **18**(4): 203-8.

Relationship of the Optic Nerve to Sphenoid Sinus.
TABLE 6
An Optic Canal Bulge is seen in 74% of cases and prominently noted in 32% of cases. The optic nerve was noted to be radiologically dehiscent in 13% of cases and had a septum inserted upon it in 8% of cases. There was no description of optic nerve dehiscence and septal insertion onto the optic nerve in the comparative study.

In 26% of cases, no Optic Canal Bulge was seen in the sphenoid sinus. These pneumatization patterns were not in significant variance to the comparative study.

RELATIONSHIP OF OPTIC NERVE TO SPHENOID SINUS		
	RESULTS OF STUDY %	BATRA, et al [1] %
0 NOT ADJACENT	3	4.7
1 ADJACENT	23	25.8
2 INDENTATION	42	39.8
3 < 50%	18	14.1
4 >50%	14	15.6
SEPTAL INSERTION	8	-
DEHISCENT OPTIC NERVE	13	-

TABLE 6

REFERENCE

1. Batra, P. S., M. J. Citardi, et al. (2004). "Software-enabled CT analysis of optic nerve position and paranasal sinus pneumatization patterns." Otolaryngol Head Neck Surg **131**(6): 940-5

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CHAPTER 9

DISCUSSION

Definitions, Limitations and Advantages in This Study.

This study has adopted radiological definitions of paranasal sinus anatomy of the frontal sinus and pneumatization patterns of the optic nerve and the internal carotid artery in relation to the sphenoid sinus as proposed by Lee and Batra. Personal communication with Citardi MJ a coauthor of the comparative papers revealed the following regarding the racial composition of patients whose paranasal sinuses were studied. The triplanar studies were conducted on patients who were not reported to have had complaints arising from sinus pathology. Lee's study was based on 50 non Asian patients comprising 44 Caucasian (88%) , 4 Blacks (8%) and 1 Hispanic (2%). Batra's studies comprised of 64 cadaver heads the racial composition of which could not be determined but could be deduced as majority non Asian reflecting the racial composition of patient population in and around Cleveland, United States of America.

In this study, the 50 subjects selected were Asian patients (80%Chinese, 8% Malays, 8% Indians and 4% Others) who had pre-operative triplanar CT scans and the majority of these patients had anteriorly based sinus disease. The main pathologies were nasal polyposis and sinusitis affecting the frontal, anterior ethmoid and maxillary sinus. Further inclusion criteria were that no previous sinus surgery had been performed as this would have made interpretation of paranasal sinus anatomy meaningless and that soft tissue disease was not so gross as to obscure the configuration of air cells, which would have made interpretation of paranasal sinus anatomy impossible.

In terms of racial differences, the comparative papers comprised mainly of non-Asians (Caucasian, Black and Hispanic) whereas my study comprised mainly of Asians (Chinese, Malay, Indian, Eurasian) with a predominance of Chinese. The subjects chosen for this study also differed from the comparative study group of Lee (patients with no sinus pathology) and Batra (cadaveric heads with no record of sinus disease) in terms of having anteriorly based sinus pathology. Choosing subjects with soft tissue disease that was not so gross as to obscure the configuration of air cells may sub-select a group of patients with less severe disease and overlook paranasal sinus anatomy of patients who had more severe disease. The anterior ethmoid sinus is the more common site infection and inflammation in this study consistent with the reports of Bolger *et al*, Calhoun *et al* and Kennedy *et al*.

Pathologies in the posterior ethmoid sinus and the sphenoid sinus in this study being less common were more directly comparable to the comparative study group of Lee, Batra and of other authors.

The apparent differences in paranasal sinus anatomy with the comparative papers are purely observational in nature. Statistical analyses have showed no significant differences between the studies. (p values all exceeded 0.005). This could perhaps have arisen from the small numbers of patients enrolled in this and the comparative studies. The purpose of this study was not to prove that there were any differences between Asian and non Asian paranasal sinus anatomy but to record observations in a study of paranasal sinus anatomy based on triplanar CT scans much like what Lee and Batra have presented for their study cohort.

A higher prevalence of the supra-orbital ethmoid cell and the frontal bulla cell is observed in this study. It is difficult to ascertain if these differences are due to ethnicity or due to a predisposition of sinuses with a higher prevalence of the above two frontal sinus cells in developing chronic infective/allergic disease.

The higher prevalence of the sphenoethmoid cell has been supported by two other Asian studies based on cadaveric dissections. (Yeoh and Thanaviratananich). The prevalence of the sphenoethmoid cell in one Asian study using single plane coronal CT views has been reported as 25% and the authors cite that the study of the Onodi cell by CT views was less sensitive than anatomical studies as has been previously proposed by Driben and Weinberger. Although this may be true for single coronal plane CT views inclusive of corresponding axial plane CT views, the previous CT studies quoted did not include a sagittal plane CT view which can show the posterior extension of a sphenoethmoid cell over the sphenoid sinus very clearly. (FIG 36,37,39). The prevalence of the sphenoethmoid cell in this study is 55%, a closer figure to Asian cadaveric dissection based studies than to Asian CT based studies.

Comparisons with Existing Literature.

A review of otolaryngology literature shows that the classification of frontal sinus cells is still in evolution. Bent and Kuhn revisited Van Alyea's 1941 frontal sinus cell classification in 1993, focusing on the anterior group of frontal sinus cell, Types I to IV and ignoring the posterior and medial groups of frontal cells. Their studies were based on single coronal plane CT views and reports of finding Type III and IV cells were limited to 8 out of 500 CT views reviewed. (1.6%). Van Alyea had reported 63 out of 242 specimens (26%) based on cadaveric dissection studies. Bent and Kuhn's methodology of study based on single plane coronal CT views clearly under reported the prevalence of Type III and IV cells then. Owen reported on the supraorbital cell in 1997 citing a prevalence of 15% and showing that a meaningful classification of the frontal sinus cells cannot ignore the posterior group which can play a significant role in frontal sinus obstruction. Wormald stressed the importance of the *agger nasi* cell as the key to understanding the anatomy of the frontal sinus in 2003, inadvertently reviving Van Alyea's classification by adding the posterior group of cells into Bent and Kuhn's proposed classification of 1993 which had not included the posterior group of cells. Wormald however left out the supraorbital ethmoid cell and his building block approach to the frontal recess was based on coronal plane views with a few sagittal views to demonstrate its advantages. Kim *et al* in 2001 reviewed computed tomography scans of 50 adult cadaver heads taken sagittally at 1-mm intervals and coronally at 3-mm intervals to study the frontal recess which was termed the nasofrontal duct. One hundred specimens, made up of sagittally divided adult cadaver heads were also dissected under the microscope to study the frontal recess. It is interesting to note their findings in detail. The study identified the anterior, posterior, medial, and lateral boundaries of the frontal recess. Kim *et al* reported that in the most common type, the superior portion of the uncinate process formed the anterior border and the superior portion of the *bulla ethmoidalis* formed the posterior border of the frontal recess. The conchal plate (middle turbinate) formed the medial border and the "suprainfundibular" plate formed the lateral border of the frontal recess. It was concluded from the study that to widen the frontal recess, removing the upper portion of the ground lamella of the ethmoid bulla, which is the posterior boundary of the frontal recess, with cutting forceps seemed to be a safe and easy method. The study of Kim *et al* emphasized the importance of the sagittal view in computed tomography and in cadaveric dissection. The introduction of a new non-standard term "suprainfundibular" plate did not cast further illumination on frontal recess anatomy and this term has not been widely accepted nor cited.

A practical classification of the frontal sinus and recess should be achievable pre-operatively and not be based on cadaveric anatomical studies. It should include a sagittal view of the frontal recess without which it would not be possible to describe the frontal sinus cells completely. The classification of Lee *et al* based on triplanar CT views satisfied these criteria. It should be noted that Kuhn is one of the co-authors with Lee in this paper and the reported incidence of frontal sinus type III cells in 2004 was 8% , a significantly higher value than 1.6% reported in 1993. Triplanar CT views based on surgical navigation protocols however, is not available in most hospitals as surgical navigation tended to be reserved for what is perceived to be difficult or revision cases.

The *agger nasi* cell (FIG 5) is more constantly identified using a radiological method (92%) , as is in this study, than compared to anatomic studies based on cadaveric dissection specimens.(10% to 89%).

The high incidence of the supra-orbital ethmoid cell (FIG 12) in this study (73%) and in the comparative study (62%) is well worth noting. Previous studies based on cadaveric dissections reported an incidence of 5% (Dixon) , 6%(Van Alyea) , 8%(Kasper) and 15% (Owen). This discrepancy with previous reported studies can be attributed to different methodologies of study. Triplanar CT views however appear to be the more sensitive and accurate methodology being able to spot even small supraorbital cells. Recognition of the supraorbital ethmoid cell and its surgical importance is relatively recent. First mention of the supraorbital ethmoid cell and its surgical significance was made by Owen and Kuhn in 1997. This cell plays a crucial role in determining the posterior outflow tract of the frontal recess. When identified its party wall should be resected to allow unimpeded drainage of the frontal recess area. Also, it should be noted that a large supra-orbital ethmoid cell can be mistaken for the frontal sinus during surgery. This may cause the surgeon to overlook the frontal sinus and result in inadequate clearance of the frontal recess.

There also appears to be a higher incidence of Frontal Bulla cells (FIG 11) in this study series. (This Study 16% vs. Lee 9% and Van Alyea 10%) This cell also plays a crucial role in determining the posterior outflow tract of the frontal recess. When identified its anterior wall should be resected to allow unimpeded drainage of the frontal recess area. A large high reaching Frontal Bulla cell may also be mistaken for the frontal sinus during surgery. This may also cause the surgeon to overlook the frontal sinus and result in inadequate clearance of the frontal recess during surgery.

The surgical axiom that governs frontal recess surgery is that the frontal recess should always be left alone if undiseased, but once it is decided that a diseased frontal recess need to be operated upon, it has to be adequately cleared to prevent cicatrisation of the surgically exposed raw areas within the confines of a naturally narrow frontal recess. Failure to identify the supraorbital ethmoid cell and the frontal bulla cell can result in inadequate clearance of the frontal recess. Three in four subjects had a Supraorbital Ethmoid cell and about one in five subjects had a Frontal Bulla cell.

It is noteworthy that in both series, the Type IV frontal cell was not encountered. Previous reports based on coronal plane CT views may not satisfy defined criteria based on triplanar CT views in which the tail or drainage outflow of the cell is looked for on the sagittal section. Some authors believe the Type IV cell cannot exist based on embryological studies that describe the frontal cells as being derived from progressive pneumatization into the frontal sinus from ethmoidal cells inferiorly. If a Type IV cell were to develop, surely its drainage would be into the infundibulum and that would make it a Type III cell. The Type IV cell would have to arise from the ethmoid just as a Type III cell would and then progressively lose its attachment inferiorly and then drain exclusively into the frontal sinus. Its embryological development would therefore also require natural regression of its inferior attachments, a rather complex embryological development not very likely to occur spontaneously. If its drainage was not into the infundibulum and the cell sealed off in the frontal sinus, then it would have to present as a mucocele.

This report (55%) supports previous reports by Yeoh (65%) and Thanaviratananich (60%) of a higher prevalence of the sphenoethmoid cell (FIG 36,37,38) in Asians as compared to Caucasian studies reported by Delano (3%) , Lee (28.1%) and Driben (37%). In this study, no optic bulge was noted within the sphenoethmoid cell in 52% of cases as compared to Yeoh (50%). Yeoh reported that in 14.7% of his cases although no optic canal bulge was present, the optic nerve was intimately related to the posterior ethmoid sinus with an average thickness of bone separating the optic nerve from the posterior ethmoid sinus being 0.25 mm. Thanaviratananich reported measurements of the minimum amount of bone thicknesses between each Onodi cell and optic nerve to range from 0.03 to 0.54 mm (median: 0.08). As Yeoh pointed out sphenoethmoid cells which do not show an optic nerve bulge pose the greatest danger to optic nerve damage during surgery as only a very thin bony wall separates the optic nerve from the sphenoethmoid cell. The high incidence of the sphenoethmoid cell (55% to 65%) in Asians in which an optic nerve bulge is absent in 50% of cases but with the optic nerve intimately related to the sphenoethmoid cell (0.03 to 0.54 mm) is an important finding for sinus surgery in Asians.

The prevalence of Haller cells in this study was 37%. Reports on the prevalence of the Haller cell, through CT studies has ranged from 10% (Kennedy and Zinreich) to 45.1% (Bolger). This wide discrepancy has been attributed to differences in interpretation of Haller's cells, in the sample population studied and the technique in CT scanning. Of note, it is likely that Zinreich's study, published in 1988 using 3 mm CT sections , may have missed the smaller Haller cells which the 2 mm CT sections with a 0.8 mm interlace in this study have picked up. (FIG 30). The presence of Haller cells do not predispose to sinusitis as Bolger noted no significant difference in prevalence of Haller cells between patients scanned for sinus disease and those scanned for non-sinus diseases. Noting the presence of a Haller cell pre-operatively is important as the medial aspect of a large Haller cell opened at surgery may mimic the sinus ostium and cause inadequate surgical clearance of the true sinus ostium in diseased anterior sinuses. (FIG 29) The Haller cell should be considered on a patient by patient basis, noting its size, its proximity to the natural ostium of the maxillary sinus, evidence of inflammation within the cell and the presence of mucosal contact points from this cell to neighboring structures to determine its importance in contributing to anterior ethmoid disease.

Reports on the prevalence of the *concha bullosa* have also varied widely amongst investigators. The prevalence reported, through cadaveric dissection study were 9% (Lothrop), 8% (Davis), 11% (Schaeffer) and 20% (Turner), through CT studies, were 33% (Clark) and 36% (Kennedy) and through a histopathological study 80% (Goldman). The prevalence of *concha bullosa* in this study was 41% where any degree of pneumatization was considered significant and recorded to show presence of a *concha bullosa*. Differing definitions of *concha bullosa* are likely to account for the variation in reported prevalence with the extensively pneumatized concha bullosa likely to have a prevalence of about

15%. Patients with *concha bullosa* have not been found to have more ostiomeatal complex disease when compared to patients without *concha bullosa.*

Conchal type of sphenoid sinuses are rare in adults and none were found in this study. The majority of sphenoid sinuses were of the post sellar type.(FIG 43) As surgery of the sphenoid sinus mostly involves taking down of the anterior wall of the sphenoid sinus in the vicinity of the sphenoid sinus ostium for drainage, the important lateral wall structures, the optic nerve and the internal carotid artery are often observed and not violated. The pneumatization of these structures in relation to the sphenoid sinus are important with extended applications of endoscopic sinus surgery into the skull base. The internal carotid artery and the optic nerve were easily identified as bulges in the lateral wall of the sphenoid sinus in 92% and 74% respectively. Septae inserting on to the internal carotid artery and optic nerve were 50% and 8% as compared to 37.5% (Batra) and 4% (Fujii) respectively. It is a surgical axiom to dissect only centrally when working within the sphenoid sinus. Any septum within the sphenoid sinus if required to be removed, should be cut and not avulsed to prevent inadvertent injury to the optic nerve and internal carotid artery.(FIG 50).

The prevalence of dehiscence of the internal carotid artery has been reported as 19.5% (Batra) and 20% (Kennedy). There were no dehiscent internal carotid arteries in the sphenoid sinus found in this study. The prevalence of dehiscence of the optic nerve has been reported as 4% (Renn) and 5% (Kennedy) as compared to 8% in this study. An anatomical study based on coronal plane CT views of Thai patients reported the prevalence of dehiscence within the sphenoid sinus of the internal carotid artery to be 10.2% and the optic nerve to be 18.2% (Nitinavakarn). There appears to be a lower prevalence of dehiscence of the internal carotid artery (noting the caveat of CT windowing and its effect on showing a bony rim around the internal carotid artery) and a higher incidence of dehiscence of the optic nerve within the sphenoid sinus in Asian populations studied.

Pneumatization of the posterior ethmoid cells postero-superiorly and the sphenoid sinus superiorly seems to be more prominent in Asian paranasal sinuses given that there were no conchal sphenoid sinuses reported in the Asian studies reviewed, that the sphenoethmoid cell is more prevalent in Asians and that there is a higher prevalence of dehiscent optic nerves and of the optic canal bulge in the Asian sphenoid sinus.

This method of using triplanar CT views to interpret paranasal sinus anatomy is superior to that of using single coronal plane CT views alone. For example, single coronal plane CT view may apparently show a Frontal Bulla cell, seen clearly on sagittal section, as a Type IV Cell. (FIG 11). Frontal recess anatomy cannot be accurately determined without the sagittal plane CT view. Further advances in pre-operative radiological assessment of the paranasal sinuses lie in this direction. The main constraint for most radiological departments not being able to provide additional axial and sagittal plane CT views is due to additional costs involved.

It is difficult to comment on whether sinus anatomy can predispose to development of disease due to obstruction of sinus outflow tracts based on this study. The numbers are too small for statistically significant analyses to be concluded between undiseased sinuses (Lee and Batra) and this study. When Haller cells (infra-orbital cells) and *Concha bullosa* (pneumatized middle turbinates) were first described, it was postulated that these cells predisposed patients developing sinusitis due to the proximity of these structures to the sinus ostium, the main drainage pathway of the maxillary sinus. This assumption has not been proven. Sinusitis is more likely a disease of obstruction of the sinus outflow tracts arising from physiologic disturbances caused by an allergic and infective cause and accentuated by the relatively narrow outflow tracts of the sinuses which may be compounded by the existence of complex paranasal sinus air cells such as a Type III frontal cell , a Haller cell or a *Concha bullosa* .

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CHAPTER 10

CONCLUSION

This thesis is based on primarily on an observational study of triplanar CT views of the paranasal sinuses of fifty Asian patients with a mean age of 45.9 years who underwent pre-operative CT scans for sinus disorders. The technology enabling this study is derived from surgical navigation protocols.

This study observed a higher prevalence of supraorbital ethmoid cells, frontal bulla cells, sphenoethmoid cells and dehiscence of the optic nerve within the sphenoid sinus and a lower prevalence of dehiscence of internal carotid artery in the sphenoid sinus as compared to studies on non-Asian patients with non-diseased paranasal sinuses. Pneumatization of the posterior ethmoid cells postero-superiorly and the sphenoid sinus superiorly seems to be more prominent in Asian paranasal sinuses

Although the higher prevalence of the sphenoethmoid cell in Asians is well established, the higher prevalence of the supraorbital ethmoid and the frontal bulla cells being due to an ethnic difference or to a higher incidence in diseased anterior sinuses could not be conclusively ascertained due to the cohort of Asian patients with diseased paranasal sinuses selected in this study as compared to non Asian patients with non-diseased paranasal sinuses from Batra’s study.

The higher prevalence of the sphenoethmoid cell in Asians, the absence of the conchal sphenoid sinus in adult Asians and the higher prevalence of a dehiscent optic nerve and the optic canal bulge in the Asian sphenoid sinus in this study and studies reviewed seem to suggest that the posterior superior aspect of the paranasal sinus of Asians to be more pneumatized than in non-Asians.

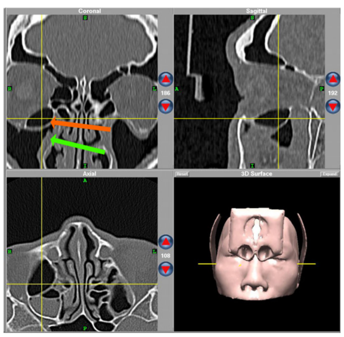
The relative small numbers of patient cohort in this and the comparative studies preclude mathematically proven statistical differences between Asian and non-Asian paranasal sinuses. Further studies with larger numbers of patients may prove or disprove the observational differences noted above.

This method of study of the paranasal sinus using triplanar CT scans is unique in providing a simultaneous view of a specific point in the coronal, axial and the sagittal view for interpretation. The study results correlate very well with findings based on single coronal plane CT views that have a better yield compared to cadaveric dissection studies, such as the prevalence of the *agger nasi* cell and with findings based on cadaveric dissection studies that have a better yield than studies based on single coronal plane CT views such as the sphenoethmoid cell. An accurate evaluation of frontal sinus cells can only be satisfactorily made with the sagittal CT view.

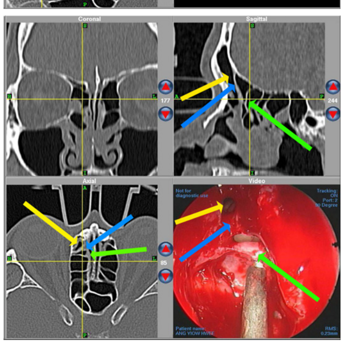
Owing to costs, radiological departments are seldom able to provide the triplanar CT view as standard pre-operative work up. With increasing use of surgical navigation, possibly reducing costs over time, triplanar CT views may in future become a standard for pre-operative evaluation prior to image guided surgery. More reports on paranasal sinus anatomy as studied using triplanar CT views will serve to validate findings of this study and that of Lee and Batra.

GUIDE TO ILLUSTRATIONS.

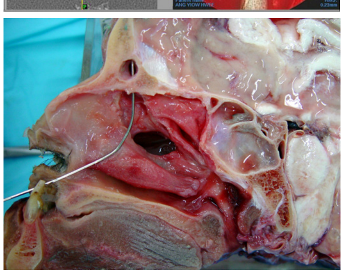
These illustrations consist of Triplanar CT Images (Coronal, Axial and Sagittal Sections) in Planning View, Triplanar CT Images in Operative View, Sagittal Cadaveric Dissection Specimens and Endoscopic Views during Surgery and of Cadaveric Specimens.
The illustrations are organized from anterior to posterior with particular references made to classification of frontal sinus anatomy and the relationship of the internal carotid artery and the optic nerve to the lateral wall of the sphenoid sinus.
The other anatomic features illustrated are the nasolacrimal duct, the anterior ethmoidal artery, concha bullosa, Haller cells and sphenoethmoidal (Onodi) cells
Significant anatomy of clinical importance is highlighted in the Operative Views which also correlate specific anatomic landmarks in triplanar CT views.
The Sagittal Cadaveric Dissection Specimens serve to provide a road map as referenced from the nostril to various anatomic landmarks in the paranasal sinuses.
References are made from the text of this thesis to these illustrations. When anatomical structures need to be indicated in these illustrations, different colored arrows or numbers are used



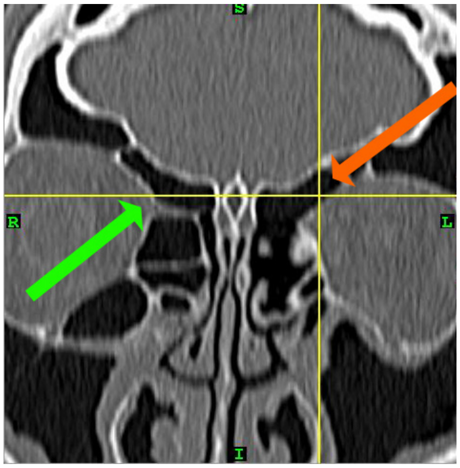
Triplanar CT Images Planning View



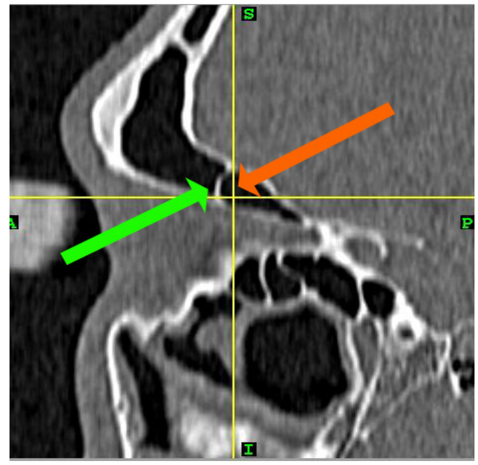
Triplanar CT Images in Operative View



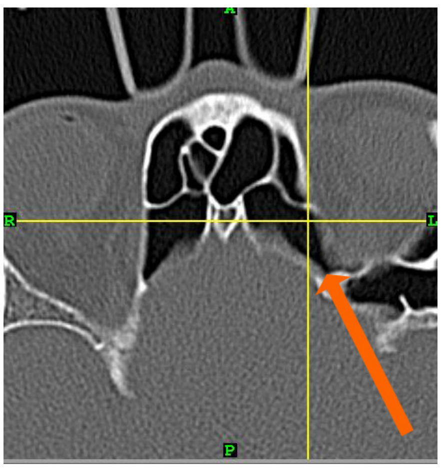
Sagittal Cadaveric Dissection Specimens



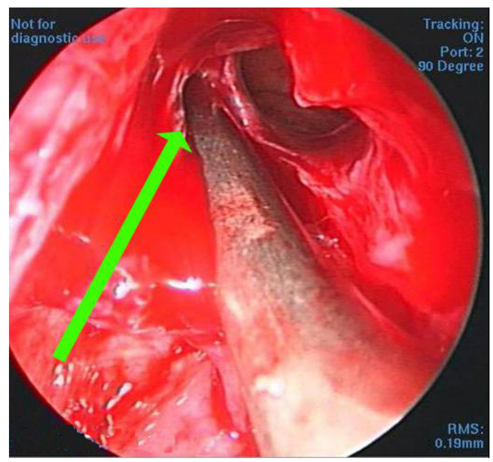
CORONAL VIEW



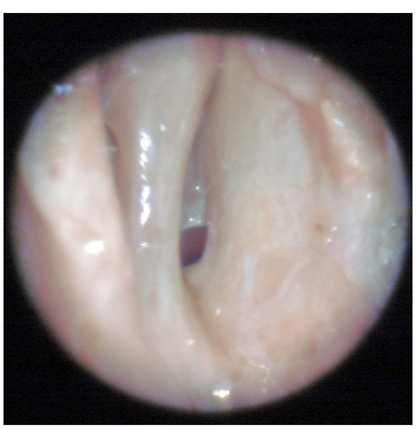
SAGITTAL VIEW



AXIAL VIEW

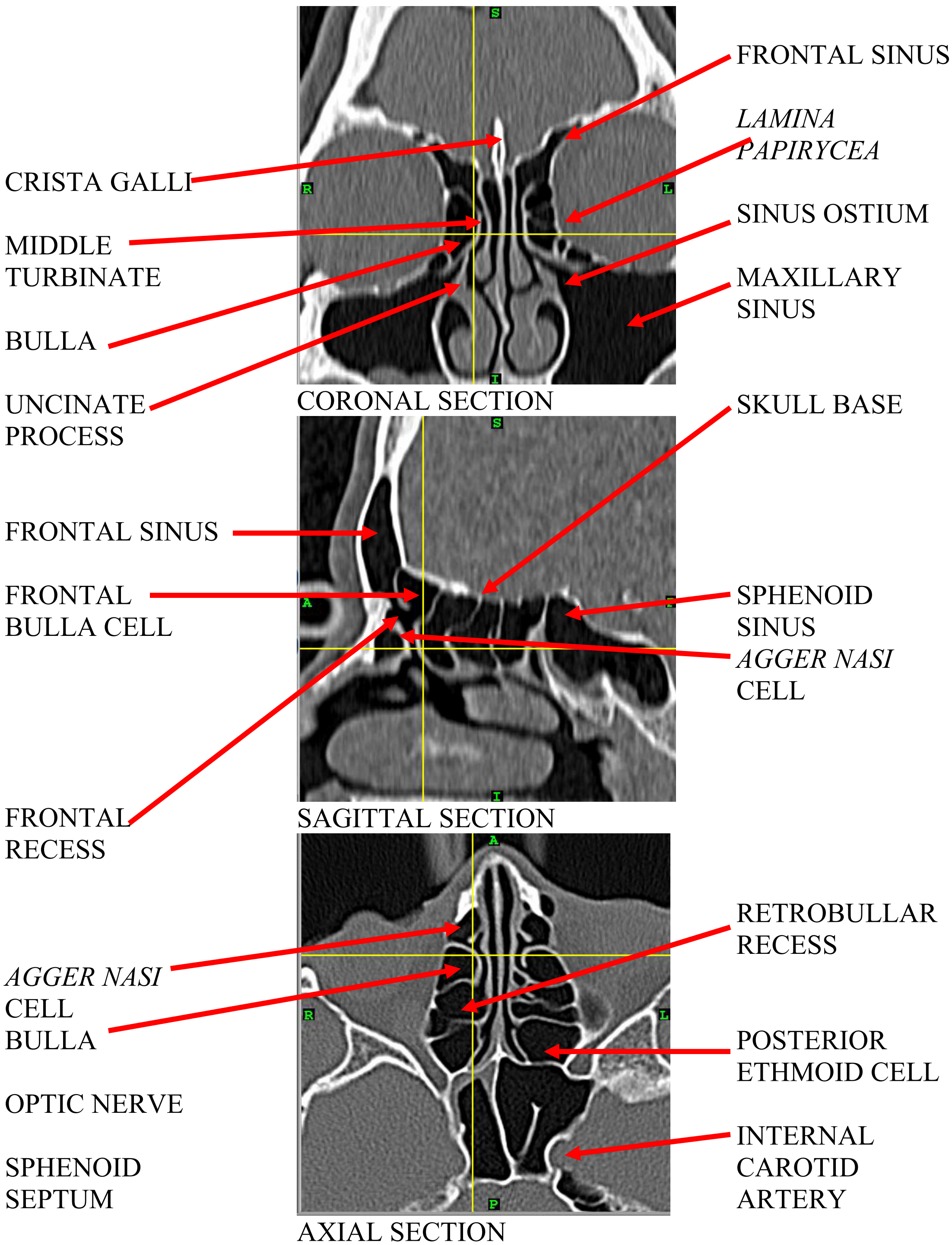


OPERATIVE VIEW

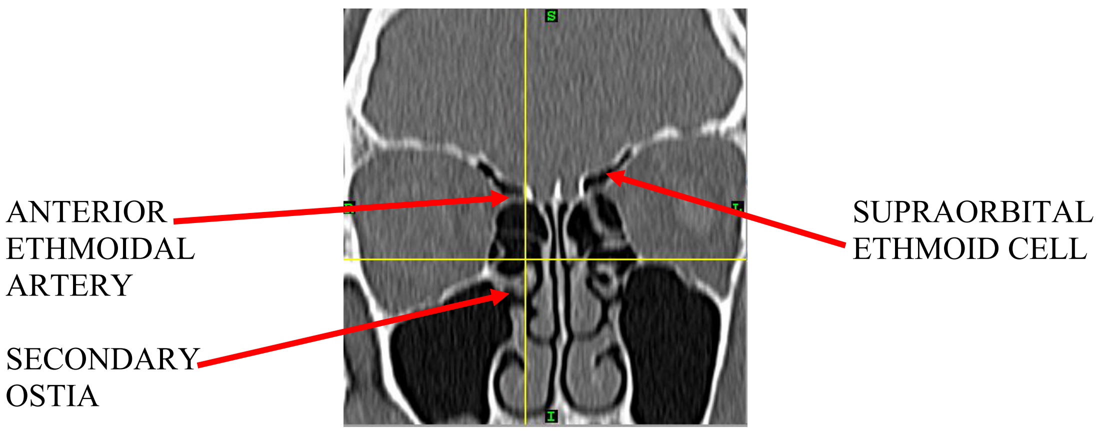


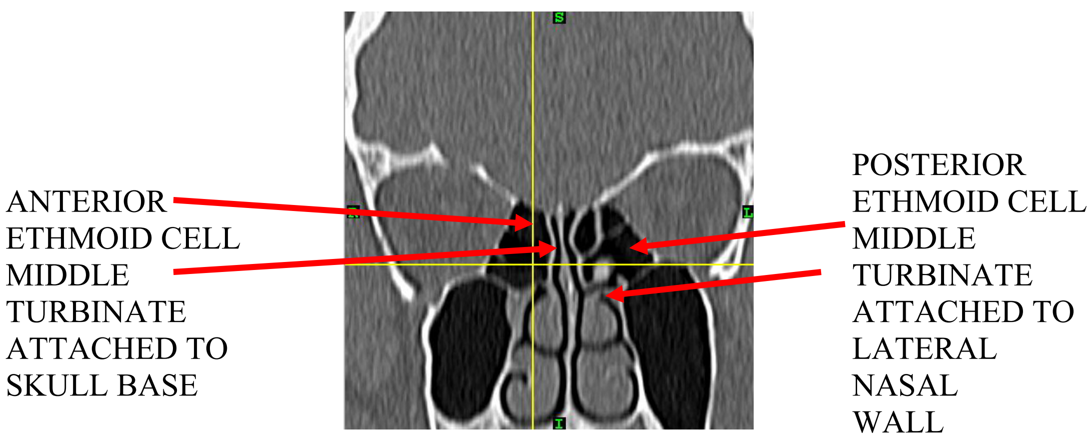
ENDOSCOPIC VIEW

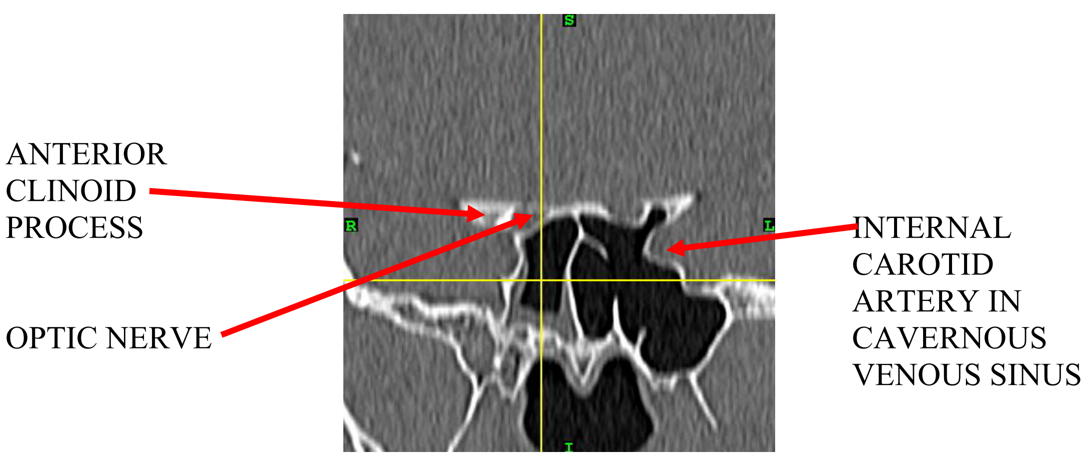
ORIENTATION TO ILLUSTRATIONS
LABELLED DIAGRAMS OF NORMAL CT SCAN ANATOMY



ORIENTATION TO ILLUSTRATIONS
LABELLED DIAGRAMS OF CORONAL VIEW CT SCANS
FROM ANTERIOR TO POSTERIOR

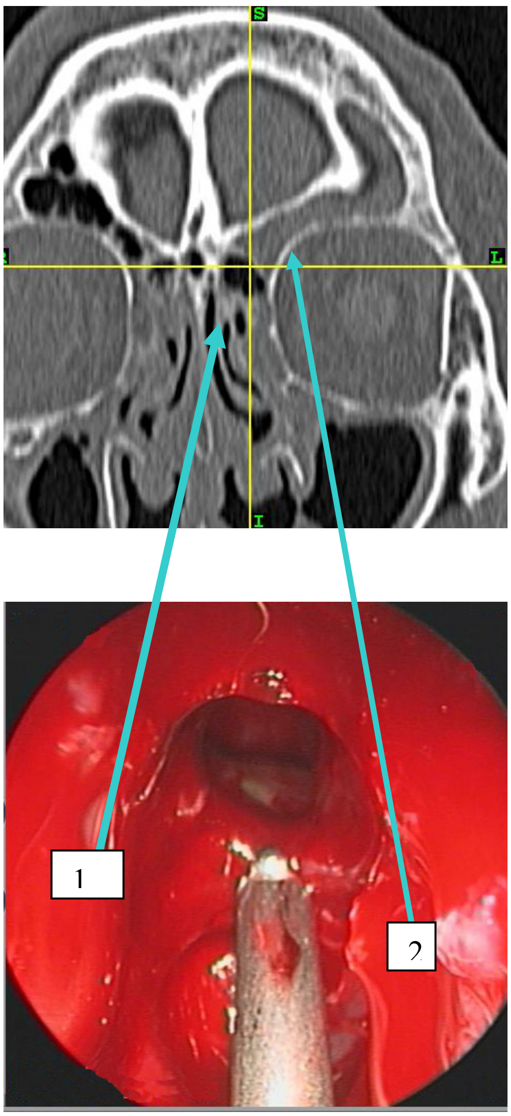






ORIENTATION TO ILLUSTRATIONS
LABELLED DIAGRAMS OF SURGICAL NAVIGATION
CORRESPONDING SITES ON CT ARE CORRELATEDWITH THE OPERATIVE VIEW BY ARROWS AND NAMED.

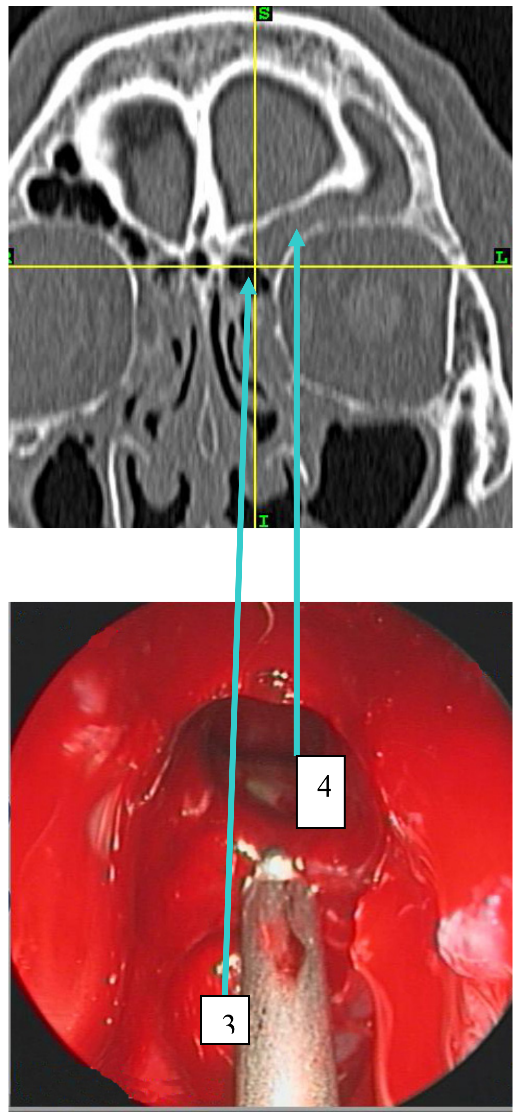
CORONAL VIEW



OPERATIVE VIEW LEFT SIDE

1 : MIDDLE TURBINATE
2 : LAMINA PAPIRYCEA

OPERATIVE VIEW
CORRESPONDS TO SIDE WHERE
YELLOW CROSSHAIRS MEET

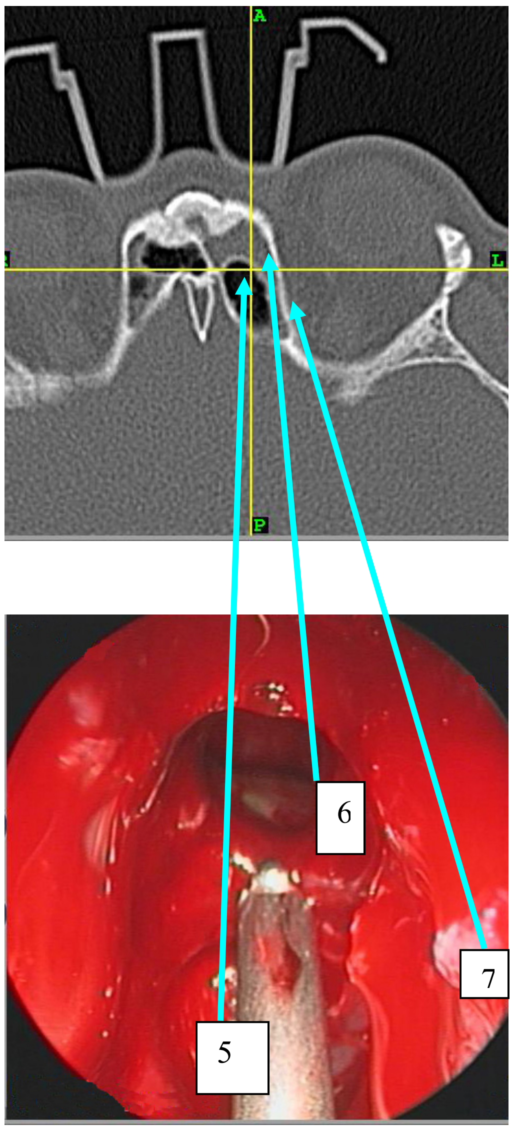


OPERATIVE VIEW LEFT SIDE

3 : SUPRABULLAR CELL
4 : FRONTAL SINUS

ORIENTATION TO ILLUSTRATIONS
LABELLED DIAGRAMS OF SURGICAL NAVIGATION
CORRESPONDING SITES ON CT ARE CORRELATEDWITH THE OPERATIVE VIEW BY ARROWS AND NAMED.

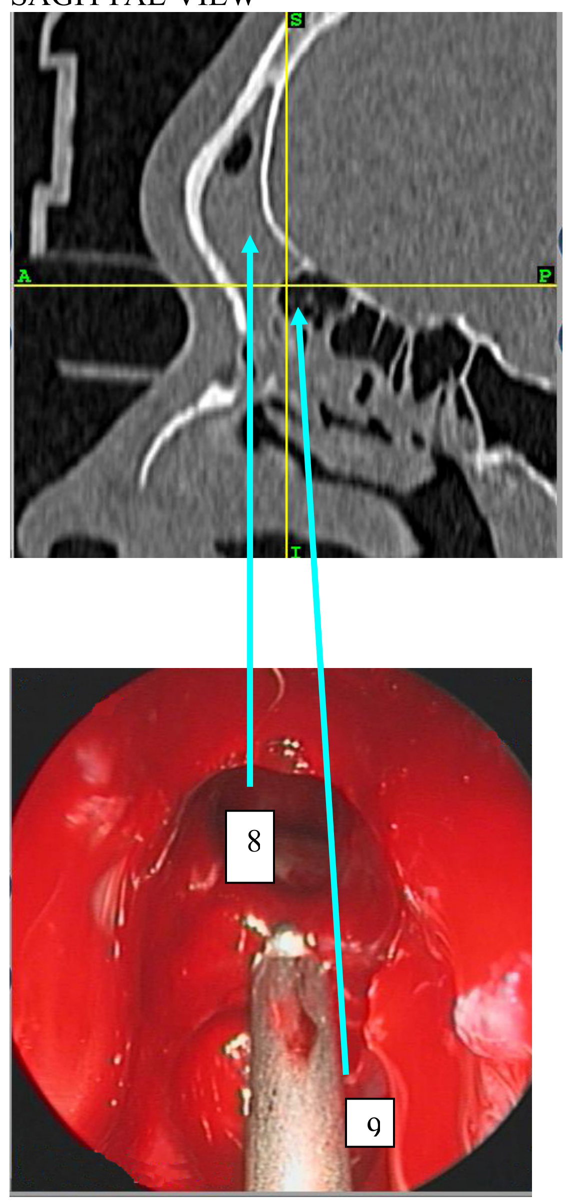
AXIAL VIEW: PATIENT IS VIEWED FROM BELOW



OPERATIVE VIEW LEFT SIDE

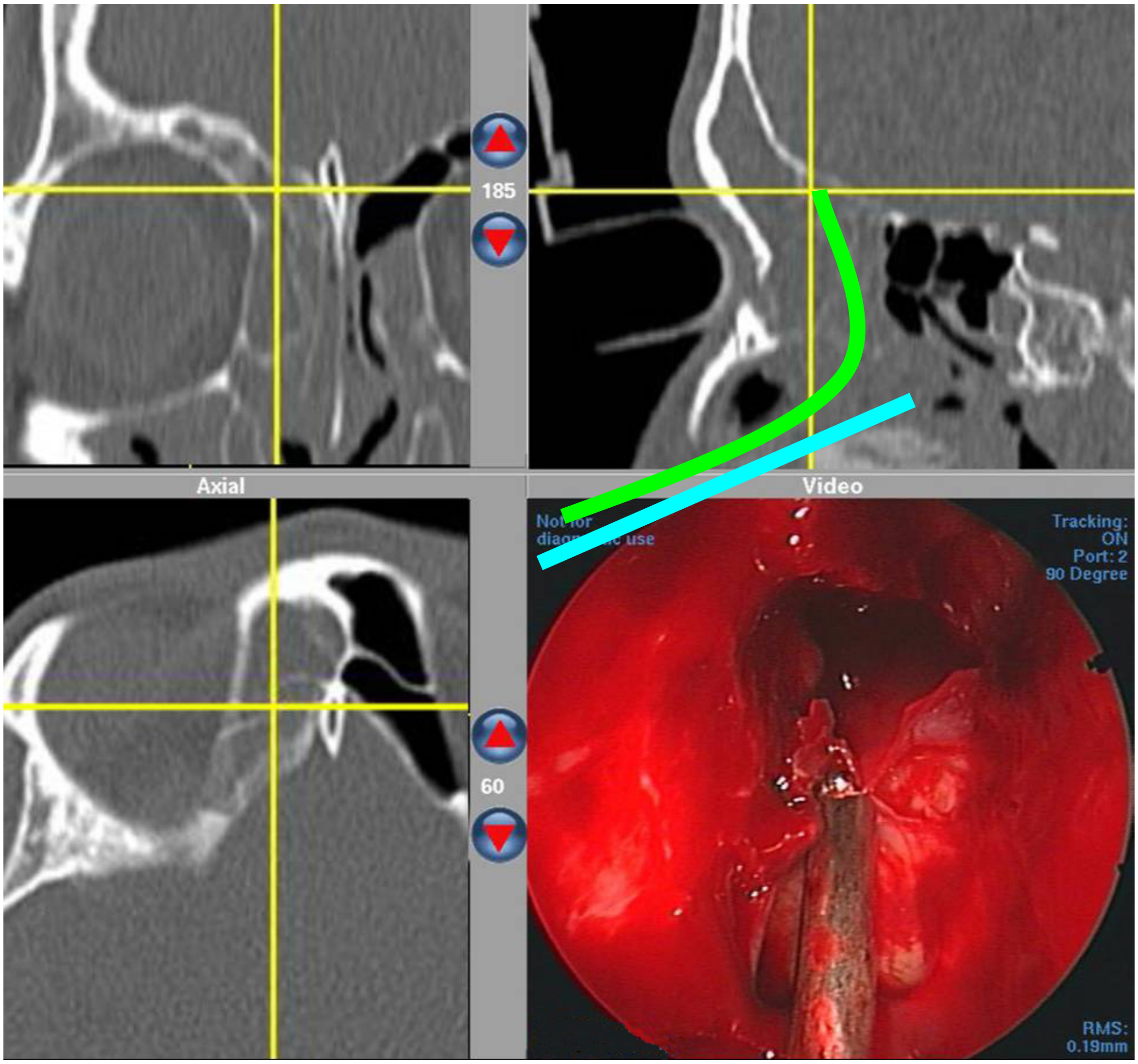
5 : SUPRABULLAR CELL
6 : FRONTAL SINUS
7 : LAMINA PAPIRYCEA

SAGITTAL VIEW



OPERATIVE VIEW LEFT SIDE

8 : FRONTAL SINUS
9 : SUPRABULLAR CELL



ORIENTATION FOR SURGICAL NAVIGATION

On the Sagittal CT View, the Green Line represents the Curved Navigation Probe placed through the nostril with its ball tip at the posterior wall of the frontal sinus. This corresponds to the end of the Curved Navigation Probe seen in the operative view.

On the Sagittal CT View, the Blue Line represents the endoscope placed through the nostril to give the operative view. Note that the scope has an angled lens such that it is looking upwards towards where the Curved Navigation Probe is.

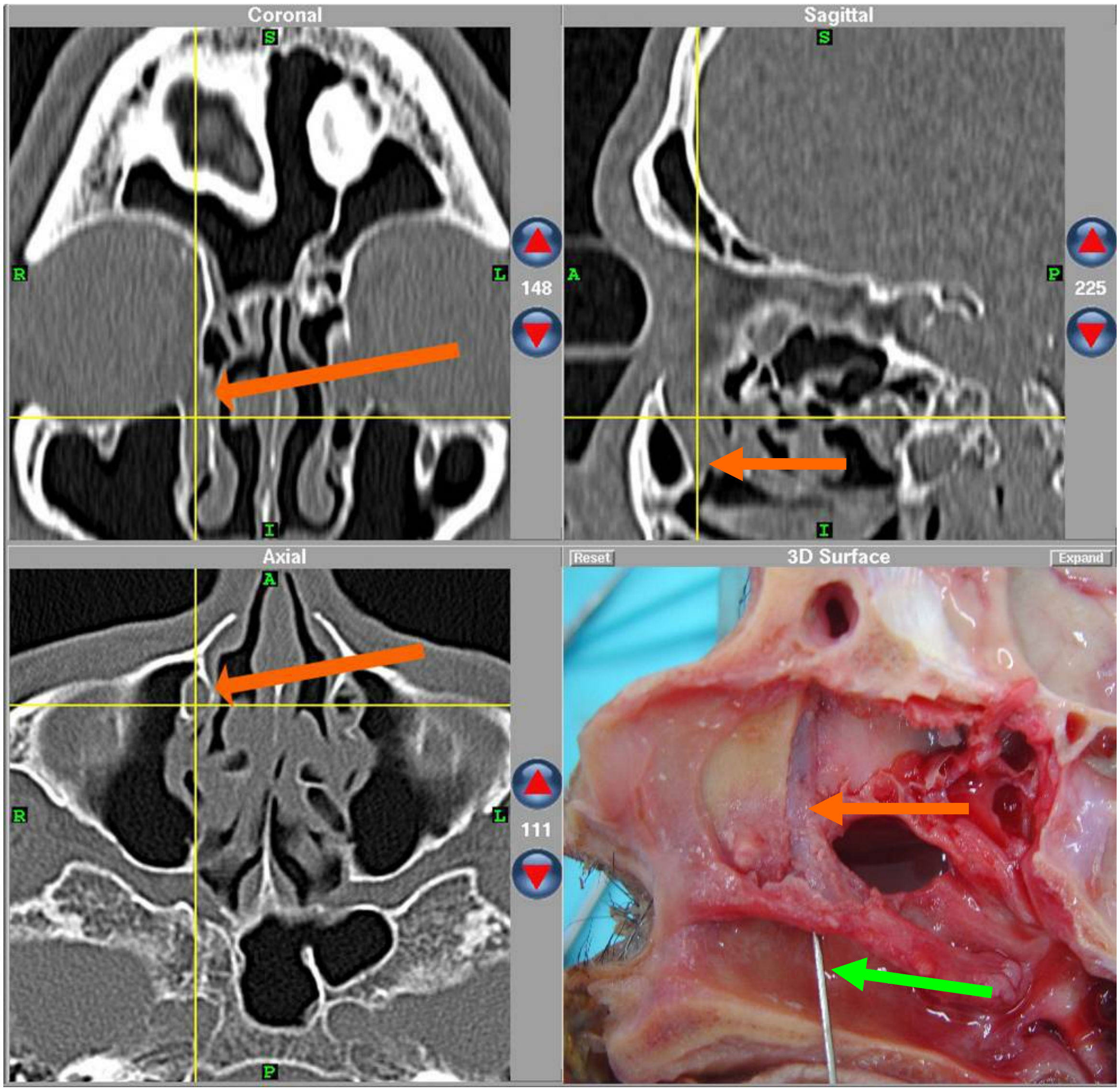


FIG 1

NASOLACRIMAL DUCT
TRIPLANAR CT IMAGES PLANNING VIEW

The Nasolacrimal Duct is the first anatomical structure identified on reviewing a coronal CT view from anterior to posterior and serves as the anterior most landmark prior to reviewing the sinuses. It is easily seen on the Coronal and Axial views and in this particular image, also on the Sagittal view of the CT and cadaveric dissection specimen as illustrated.(Orange Arrow).
The probe at the inferior end of the nasolacrimal duct indicates the site of opening of the duct into the inferior meatus. (Green Arrow)

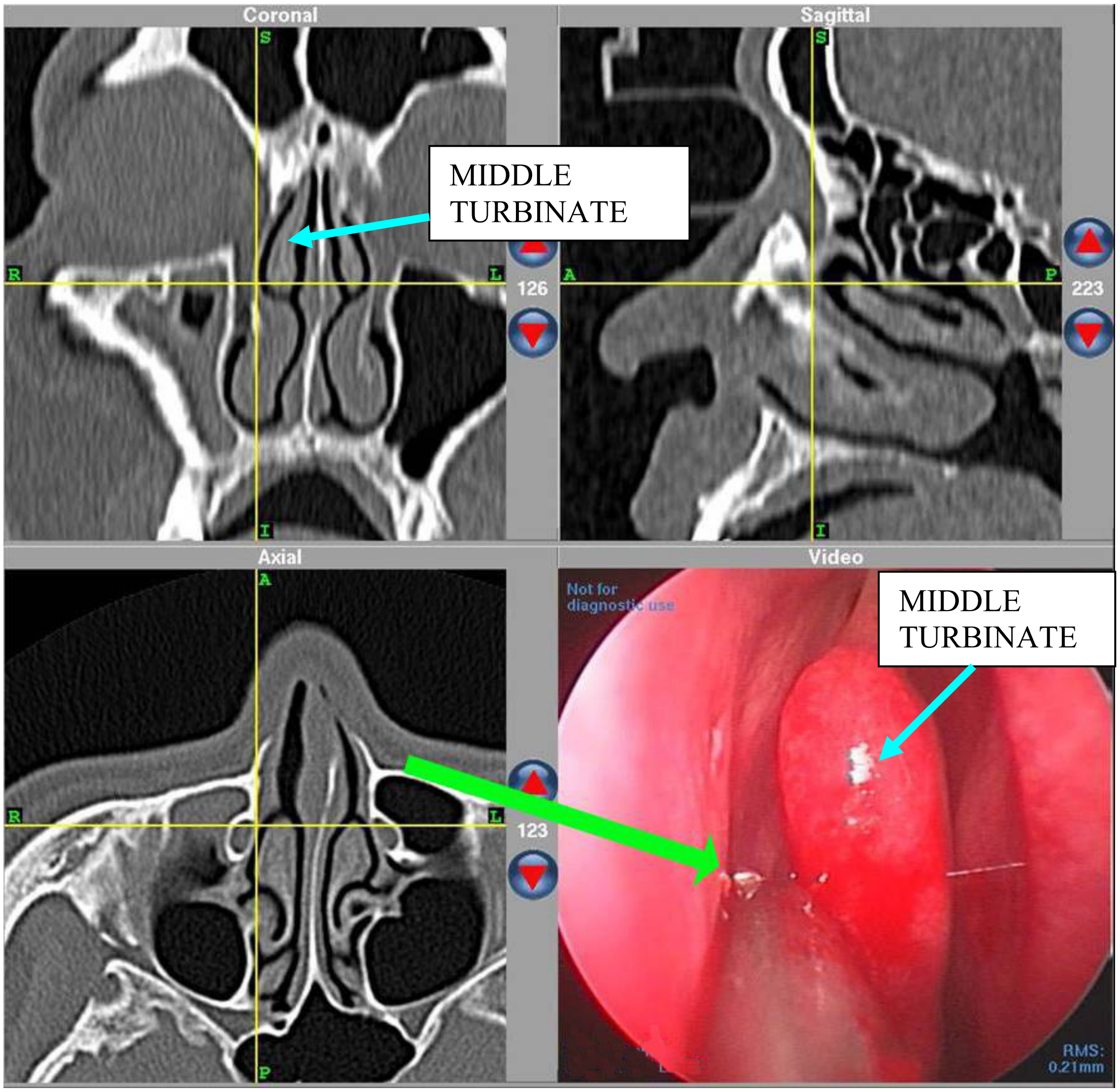


FIG 2

NASOLACRIMAL DUCT
TRIPLANAR CT IMAGES OPERATIVE VIEW

During Surgical Navigation, the Tracker (Green Arrow : Operative View) when placed just anterior to the uncinate process is shown to be just medial to the nasolacrimal duct.

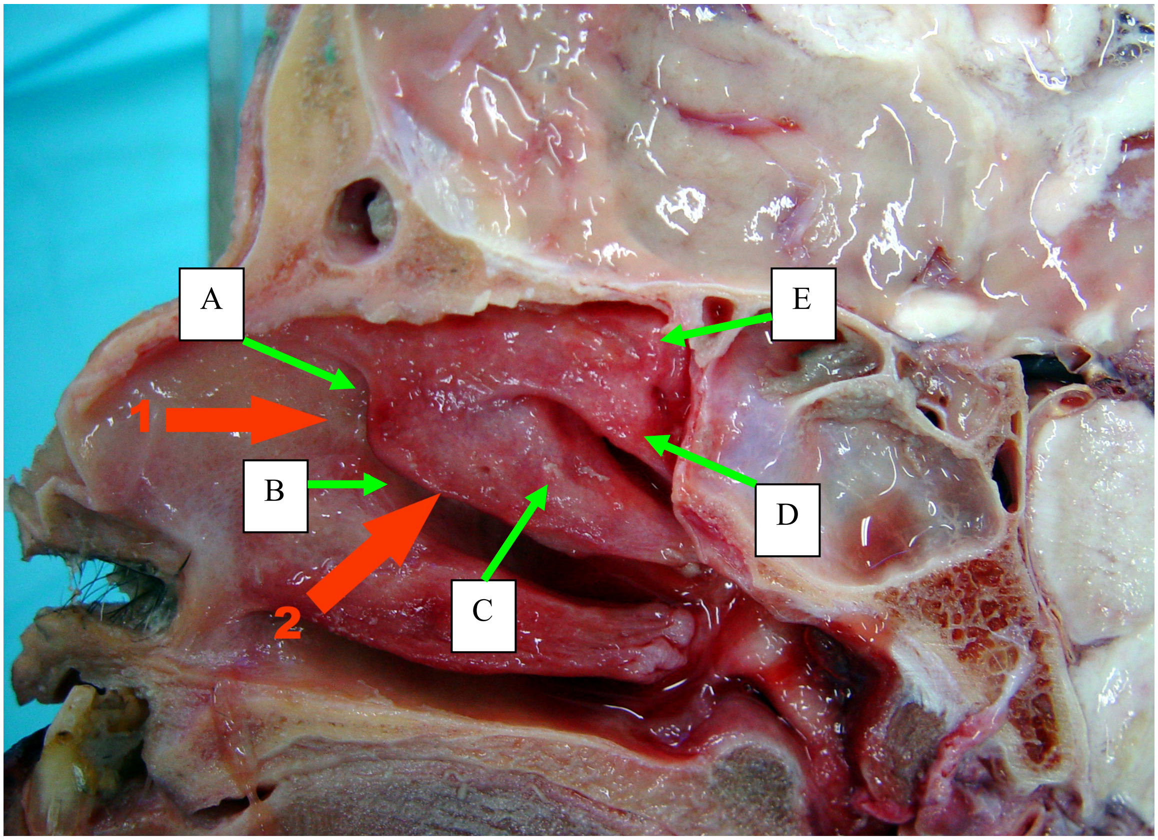


FIG 3

NASOLACRIMAL DUCT AND MIDDLE TURBINATE.
EMBRYOLOGY : THE ETHMOTURBINALS.
SAGITTAL CADAVERIC DISSECTION SPECIMEN

The nasolacrimal sac and duct (1) are situated anterior to the middle turbinate (2) and the uncinate process.

The *agger nasi* (A) is a remnant of the ascending portion of the first ethmoturbinal. The uncinate process (B) develops from the descending portion of the first ethmoturbinal.

The middle turbinate (C) develops from the second ethmoturbinal, the superior turbinate (D) develops from the third ethmoturbinal, and the supreme turbinate (E) develops from the fourth and fifth ethmoturbinals.

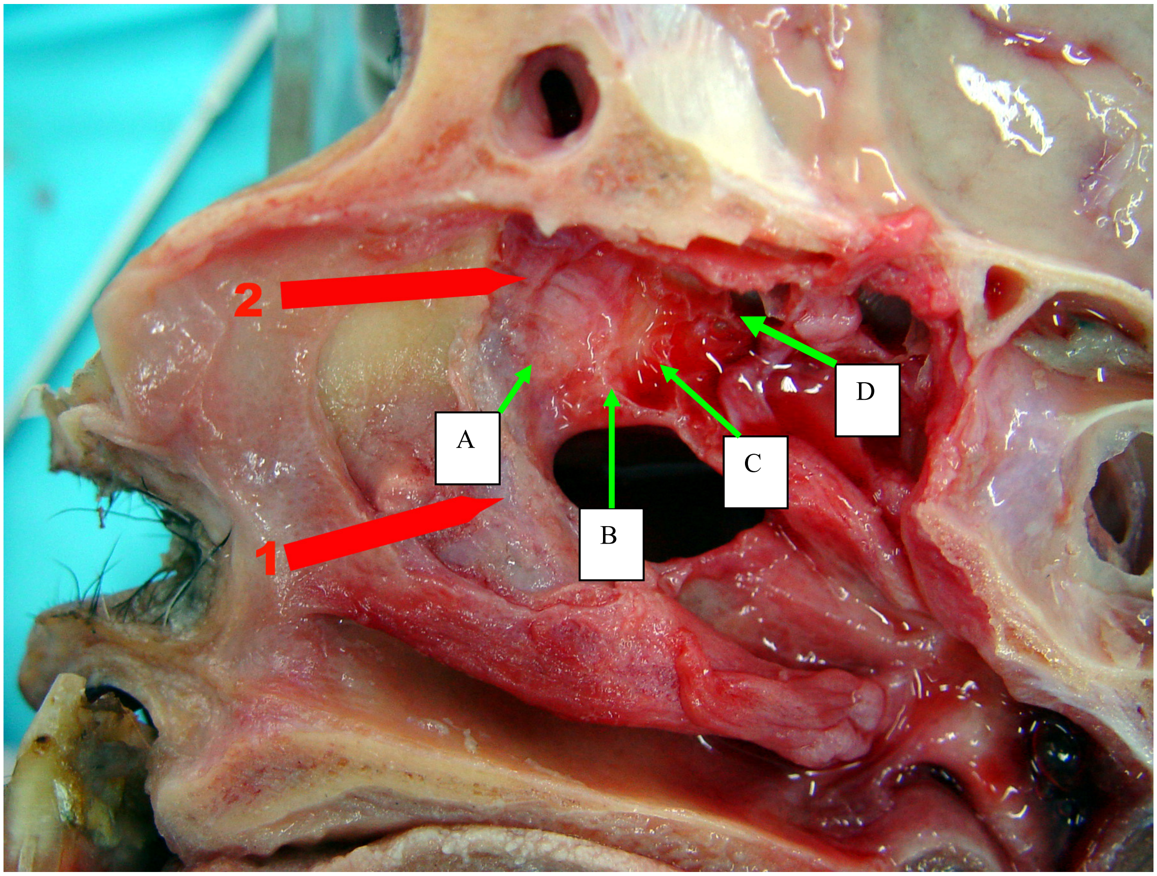


FIG 4

NASOLACRIMAL DUCT AND *AGGER NASI* CELL
EMBRYOLOGY : LAMELLAR DEVELOPMENT IN THE PARANASAL SINUS.
SAGITTAL CADAVERIC DISSECTION SPECIMEN

The Nasolacrimal Duct is exposed. Note that at its inferior aspect (1) , the nasolacrimal duct curves posteriorly assuming a closer relationship to the sinus ostium than at its superior aspect. Backbiting in this area can cause injury to the nasolacrimal duct which can possibly cause epiphora.
The First Air Cell of the Anterior Ethmoid group lies just posterior to the nasolacrimal sac and duct (2) and is termed the Agger Nasi Cell.
The significance of the embryologic development of the paranasal sinus is appreciated during endoscopic sinus surgery as the lamellar structures are encountered from anterior to posterior in this cadaveric specimen with the uncinate, ethmoid bulla, ground lamella and superior turbinate removed.
The first basal lamella (A) corresponds to the uncinate process, the second basal lamella (B) corresponds to the ethmoid bulla, the third basal lamella (C) corresponds to the base of the middle turbinate (known as the ground lamella that separates the anterior and posterior ethmoid sinuses) , and the fourth basal lamella (D) corresponds to basal lamella of the superior turbinate.

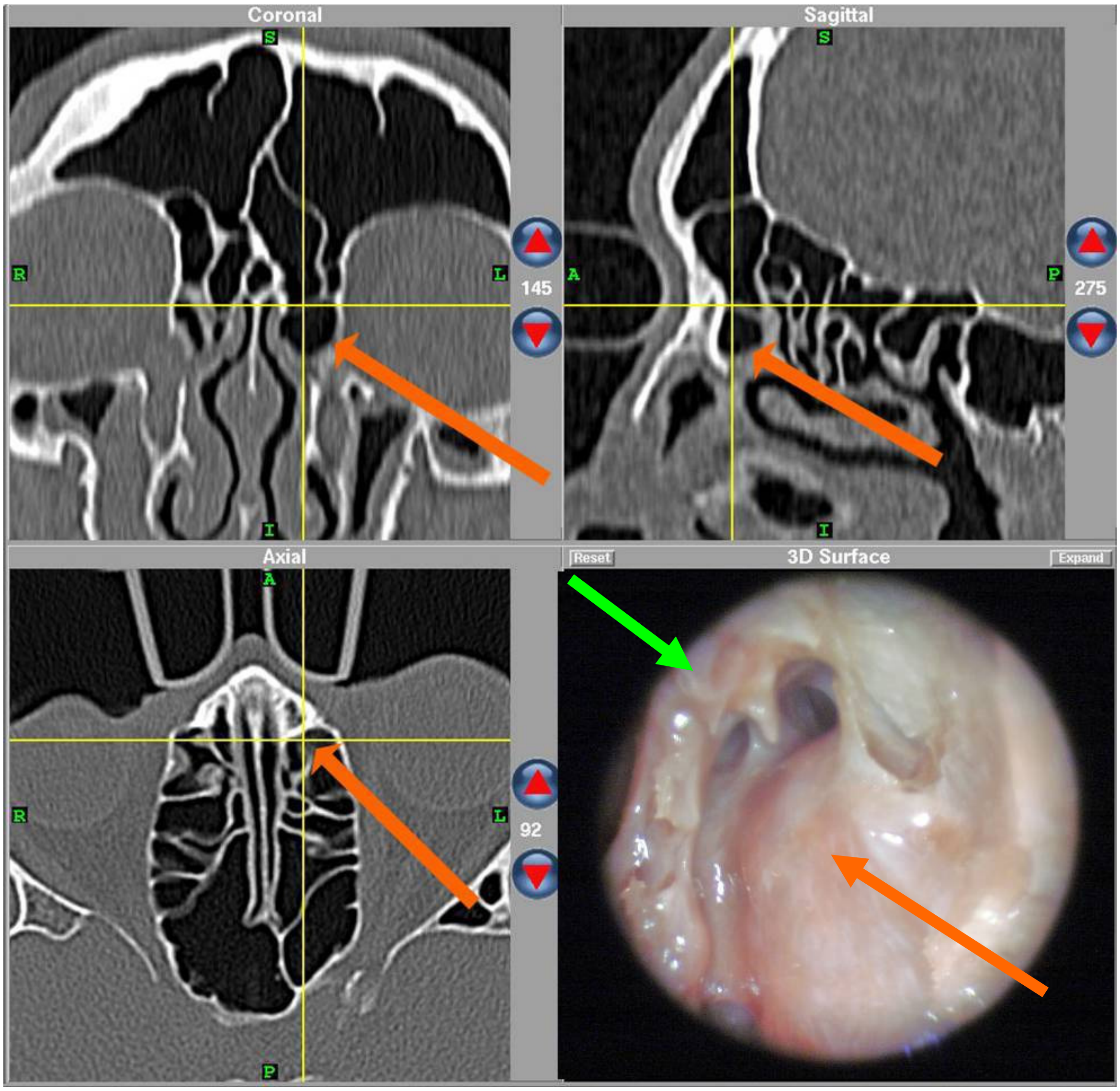


FIG 5

AGGER NASI **CELL** [1]
TRIPLANAR CT IMAGES PLANNING VIEW
ENDOSCOPIC VIEW OF CADAVERIC SPECIMEN

- “The most anterior ethmoid cell”
- Swelling along lateral nasal wall (Orange Arrow Endoscopic View) anterior to middle turbinate vertical attachment (Green Arrow Endoscopic View)
- Pneumatization of the *Agger Nasi* region
- Well seen on sagittal and coronal CT views

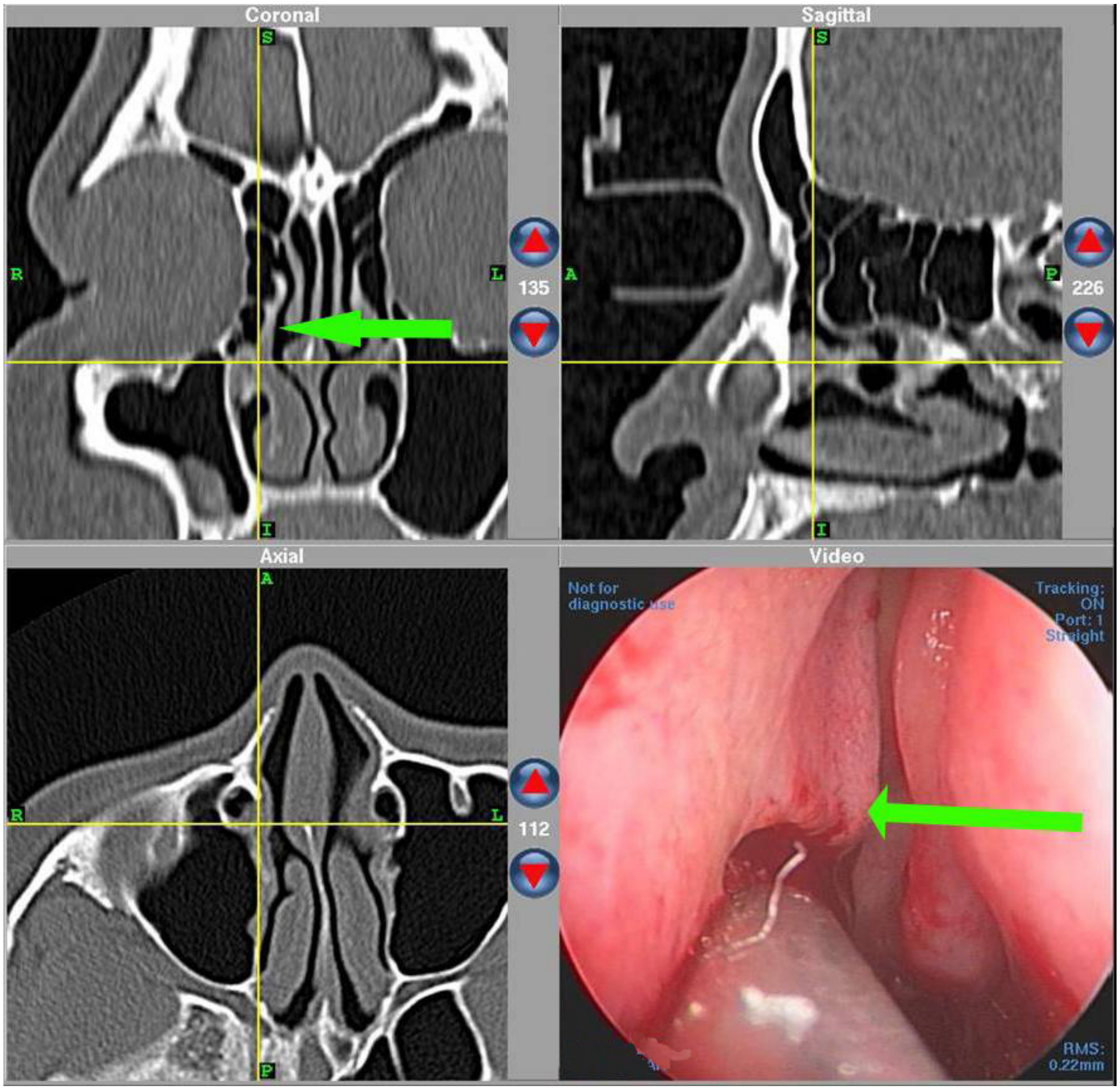


FIG 6

***AGGER NASI* CELL AND UNCINATE PROCESS.**
TRIPLANAR CT IMAGES OPERATIVE VIEW

The inferior aspect of the right uncinate process has been removed. The navigation probe (Green Arrow Operative View) is placed at the site of uncinate removal. Its position is clearly seen on the coronal and axial CT sections. (Crosshairs indicate position of the navigation probe)

The uncinate process has a close relationship to the agger nasi cell , lying just posterior to the posterior wall of the agger nasi and at times forming the posterior wall of the agger nasi cell.

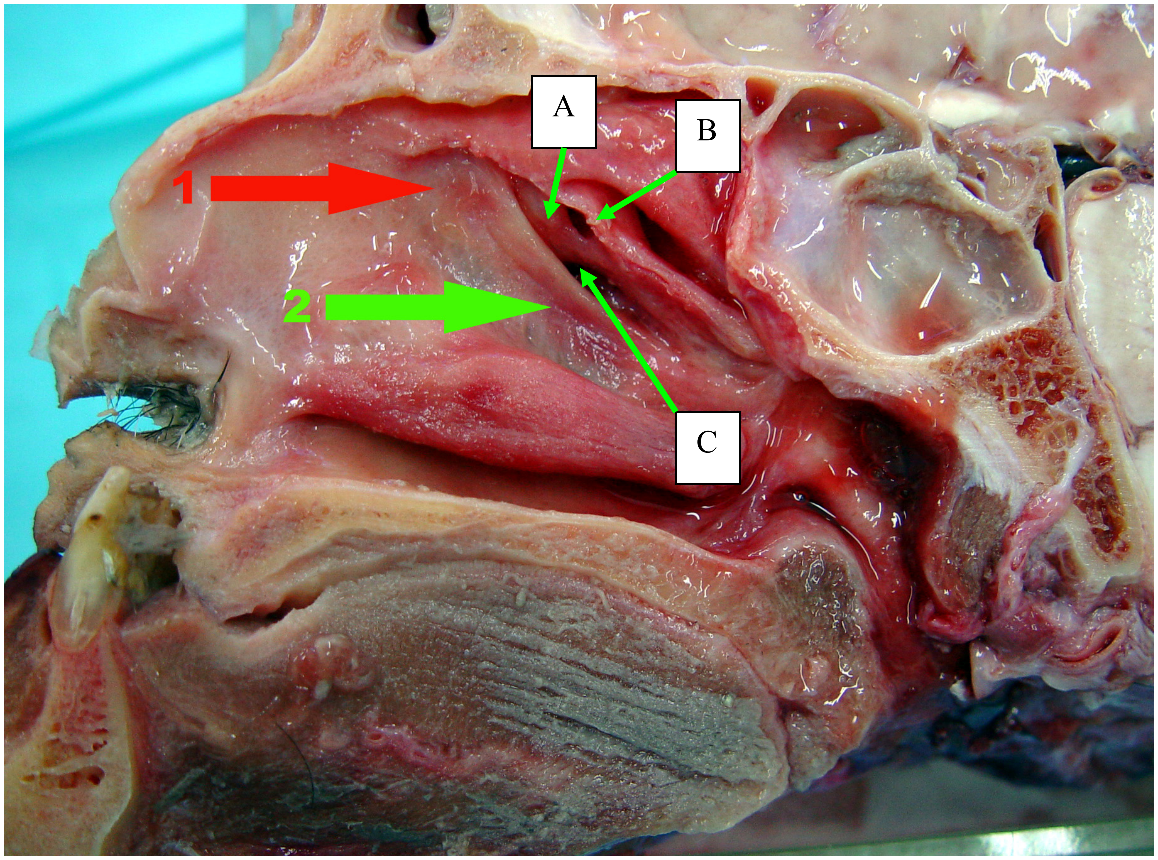


FIG 7

UNCINATE PROCESS IN RELATION TO THE *AGGER NASI* CELL
SAGITTAL CADAVERIC DISSECTION SPECIMEN

The uncinate process is illustrated (2), the arrowhead indicates the area of the uncinate process removed in FIG 2A. The uncinate process has a vertical and horizontal component. The vertical component is closely related to the frontal recess and care should be exercised when removing this part as tearing here may cause adhesions that can potentially affect the drainage of the frontal sinus. The horizontal component is removed separately from the vertical component, a remnant horizontal component is often the cause of recurrent maxillary sinusitis.

The agger nasi cell (1) is just anterior to the vertical aspect of the uncinate process. The uncinate process often forms the posterior wall of the *agger nasi* cell.

The ethmoid bulla (A) and the named spaces around it, the retrobullar recess (B), hiatus semilunaris inferioris (C) is identified.

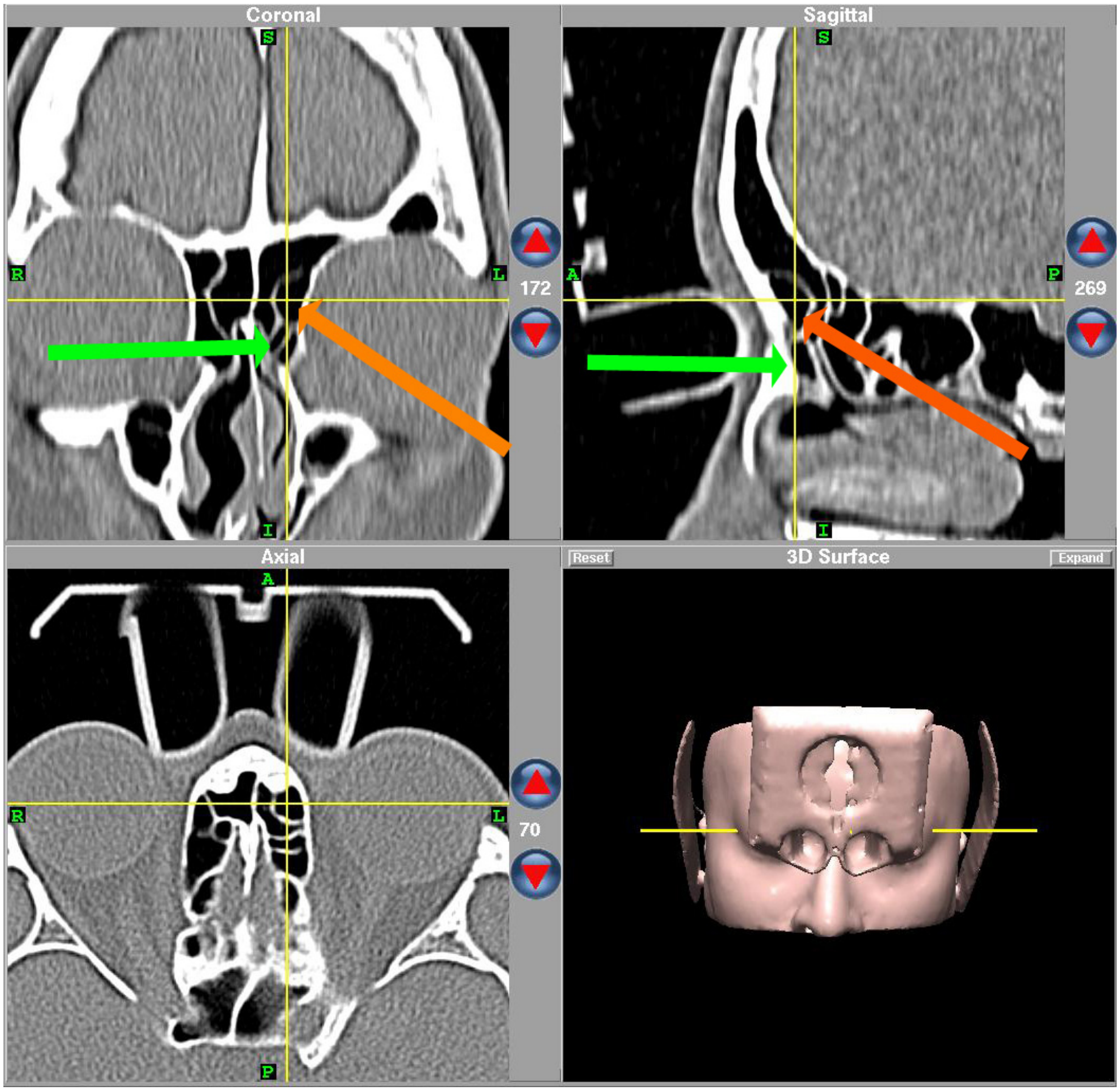


FIG 8

FRONTAL CELL, TYPE I [1]
TRIPLANAR CT IMAGES PLANNING VIEW

- Single anterior Ethmoid Cell (Orange Arrow) above the *Agger nasi* cell (Green Arrow)
- Posterior wall is not skull base; posterior wall is free partition in the frontal recess
- Well seen on coronal and sagittal CT views.

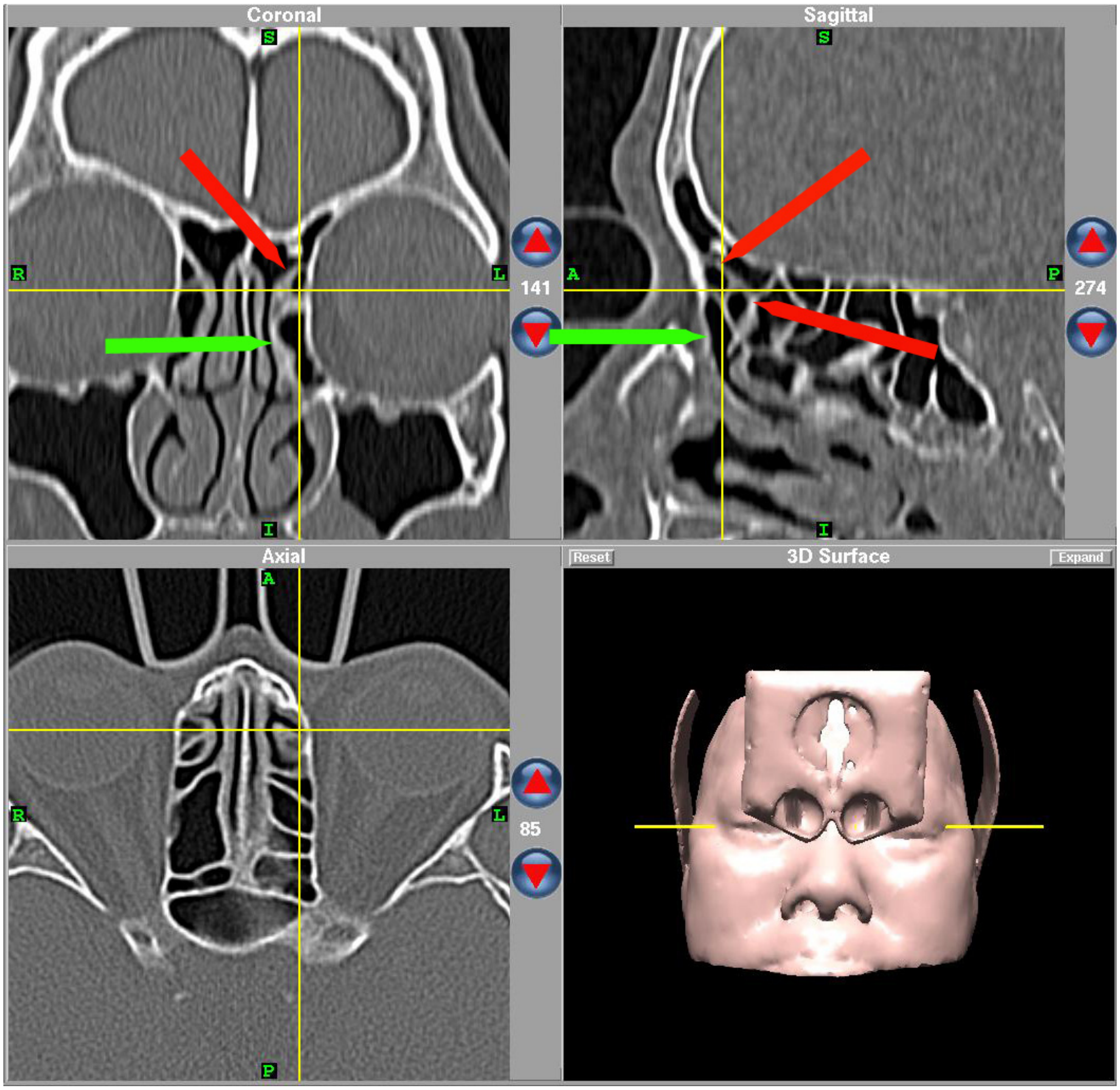


FIG 9

FRONTAL CELL, TYPE II [1]
TRIPLANAR CT IMAGES PLANNING VIEW

- Tier of 2 or more anterior ethmoid cells (Red Arrows) that pneumatize above the *agger nasi* cell (Green Arrow)
- Posterior wall is not skull base; posterior wall is free partition in the frontal recess
- Well seen on coronal and sagittal CT views

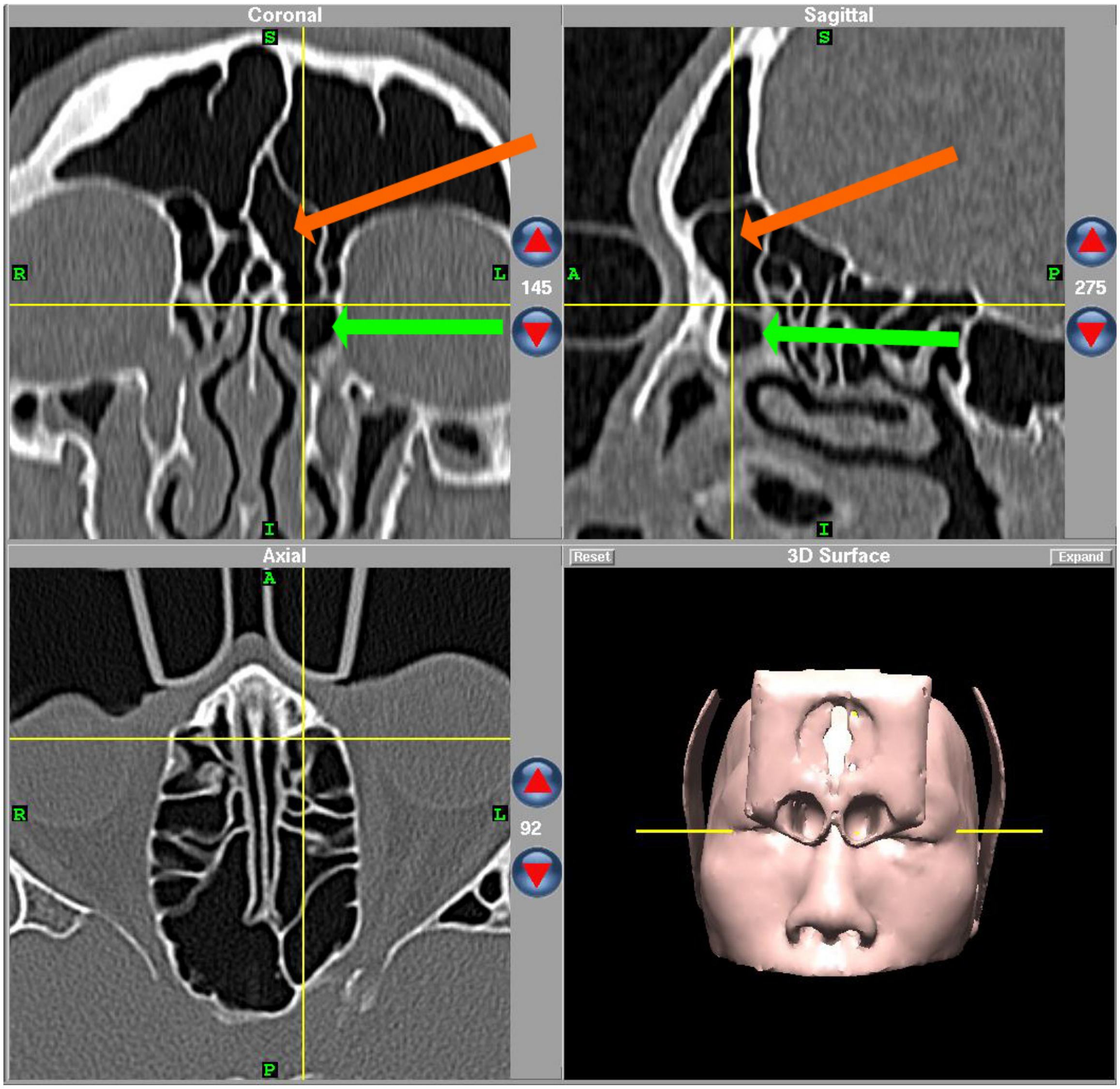


FIG 10

FRONTAL CELL, TYPE III [1]
TRIPLANAR CT IMAGES PLANNING VIEW

- Single large anterior ethmoid cell (Orange Arrow) above the *Agger nasi* cell (Green Arrow).
- Pneumatizes along inner aspect of the anterior frontal sinus table from the anterior frontal recess
- Extends far into true frontal sinus; superior wall (cap) inserts upon inner aspect of the anterior frontal sinus table (seen on sagittal CT view Orange Arrow)
- Posterior wall is not skull base; posterior wall is free partition in the frontal recess
- Well seen on coronal and sagittal CT views

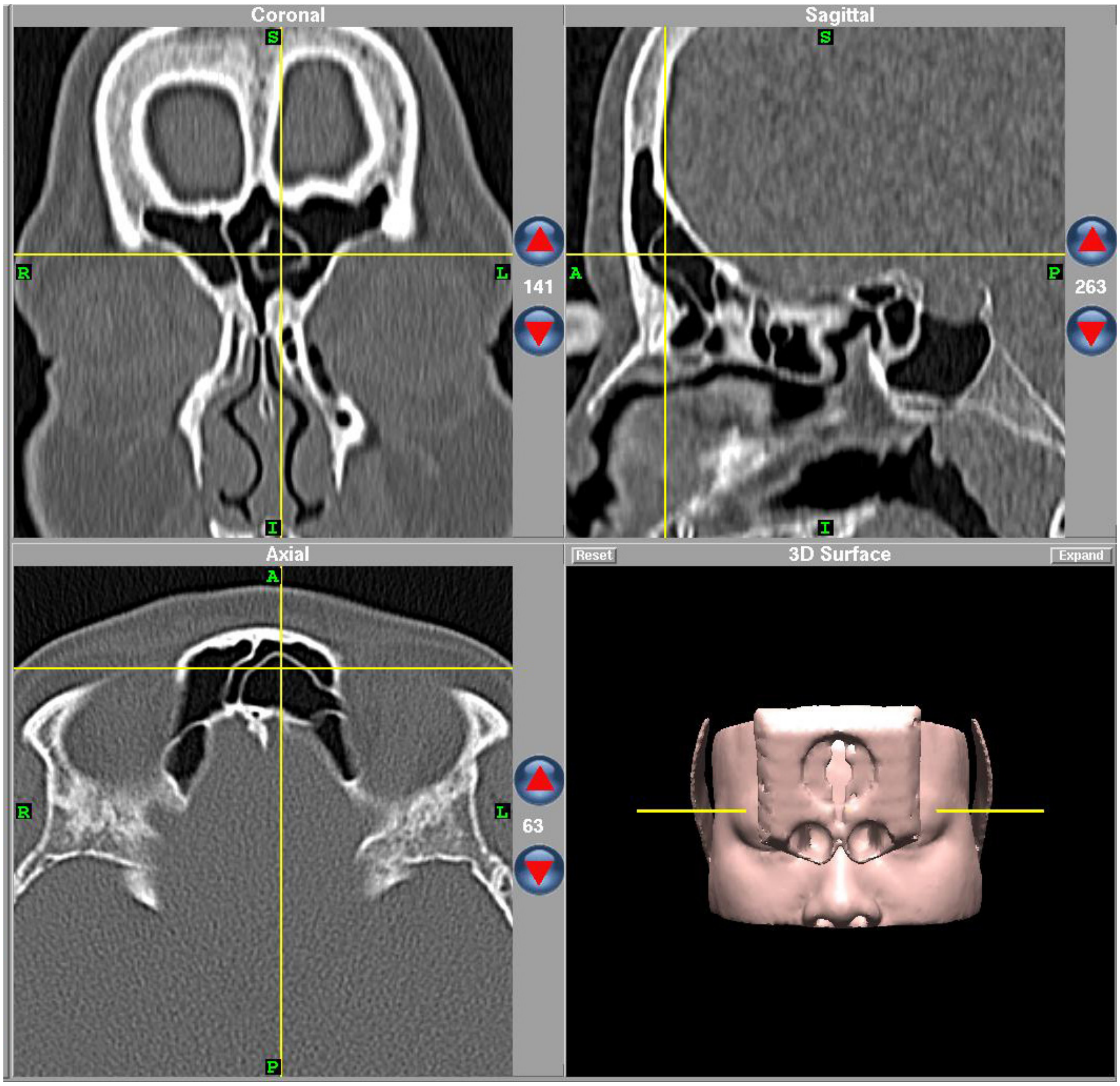


FIG 11

FRONTAL CELL, TYPE IV [1]
TRIPLANAR CT IMAGES PLANNING VIEW

- Apparently isolated cell within frontal sinus and above the agger nasi cell
- . Appears as an "air bubble " on coronal CT view
- Appears as a "balloon on a string" on sagittal CT view,
- The anterior/inferior margin is anterior frontal sinus table or frontal sinus floor
- The posterior boundary is cell wall, not posterior frontal sinus table.
- Identification requires both sagittal and coronal CT views.

Coronal View of this CT would have suggested a Type IV cell. However, Sagittal View shows this cell arising from above the bulla from posteriorly. This is a Frontal Bulla Cell and not a Type IV cell. This illustrates the utility of using Triplanar CT Views in evaluating paranasal sinus anatomy precisely as is done in this report.

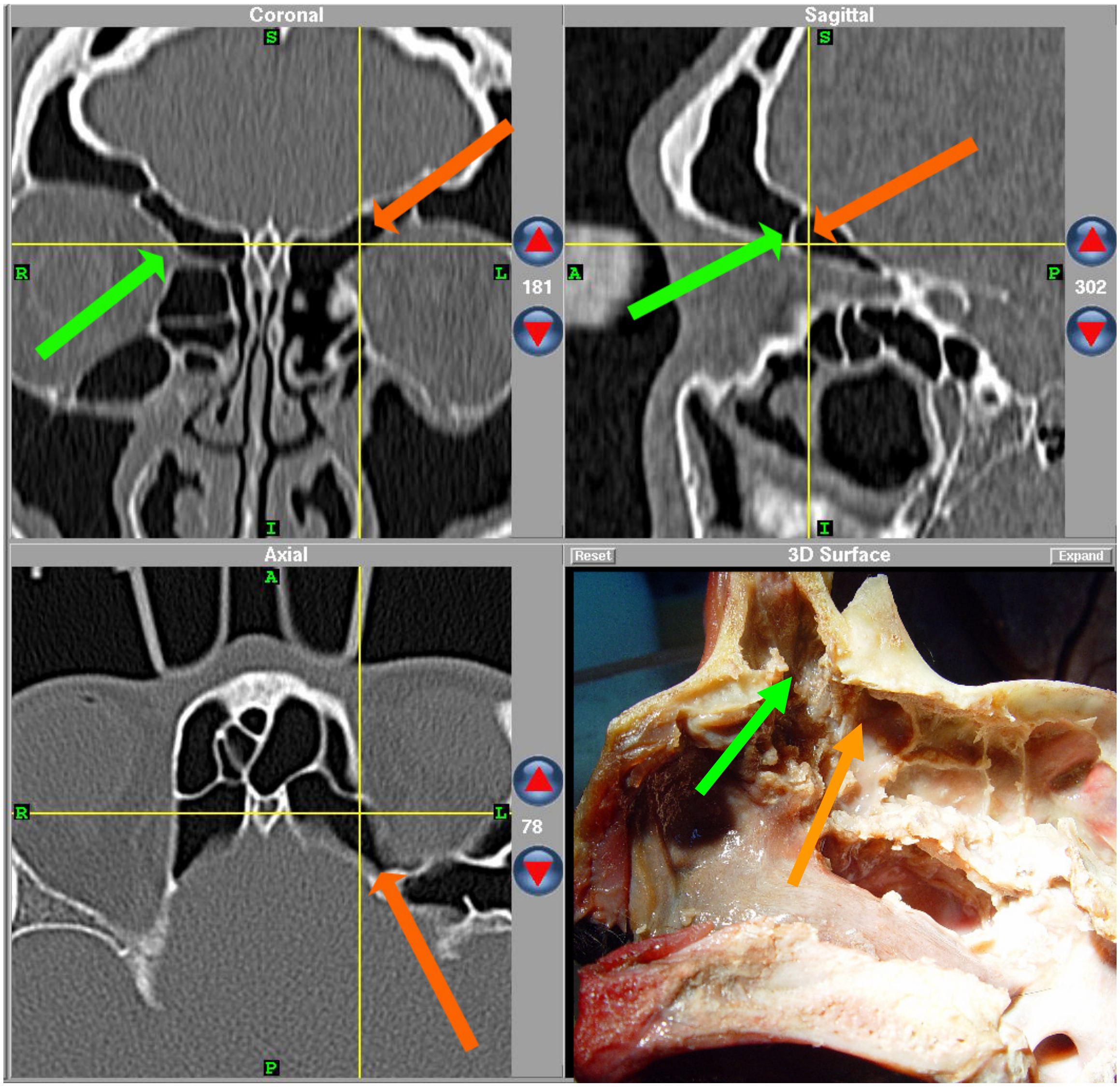


FIG 12

SUPRAORBITAL ETHMOID CELL [1]
TRIPLANAR CT IMAGES PLANNING VIEW
SAGITTAL CADAVERIC DISSECTION SPECIMEN

- Ethmoid cell (Orange Arrow Coronal) that extends over the orbit from the frontal recess
- May be single or multiple,
- May mimic the appearance of a septate frontal sinus (Green Arrow Sagittal)
- Opens into the lateral aspect of the frontal recess (This opening is lateral and posterior to the true frontal sinus ostium.)
- Identification requires review of both axial and coronal CT images.

Green Arrow Coronal shows a protrusion extending superior medially from the orbit indicating the anterior ethmoidal artery. Identification of the SOEC is often made on the Coronal View when air is seen above the anterior ethmoidal artery. This indicates that there is likely an air cell posterior to the anterior ethmoidal artery.
Orange Arrow Axial shows the ethmoidal cell extending laterally above the orbital roof.
In Cadaveric Dissection View, SOEC (Orange Arrow) is seen posterior to Frontal Sinus Os.(Green Arrow)

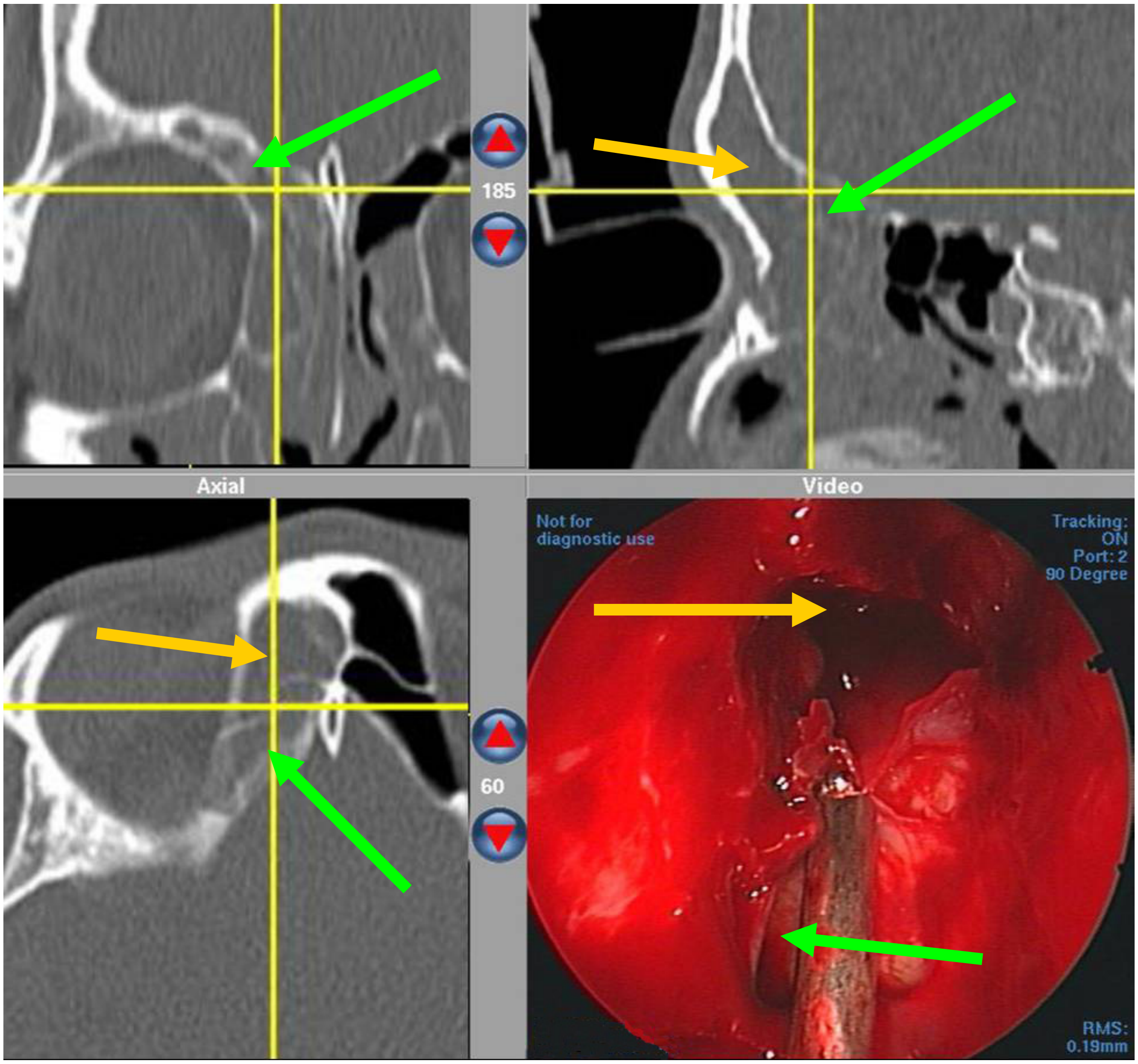


FIG 12A

SUPRAORBITAL ETHMOID CELL
TRIPLANAR CT IMAGES OPERATIVE VIEW

The tracker is placed at the party wall between the frontal sinus (Orange Arrow Operative View) and the supraorbital ethmoid cell.(Green Arrow Operative View).
The supraorbital ethmoid cell is seen in the Axial View posterior (Green Arrow Axial View) to the frontal sinus. (Orange Arrow Axial View) It is seen as a “septate” sinus (Green Arrow Sagittal View) posterior to the frontal sinus (Orange Arrow Sagittal View) on the Sagittal View. (Green Arrow Sagittal View) . On the Coronal view, it is seen as air above the anterior ethmoid artery and as a prominent lateral pneumatization over the orbit.(Green Arrow Coronal View).

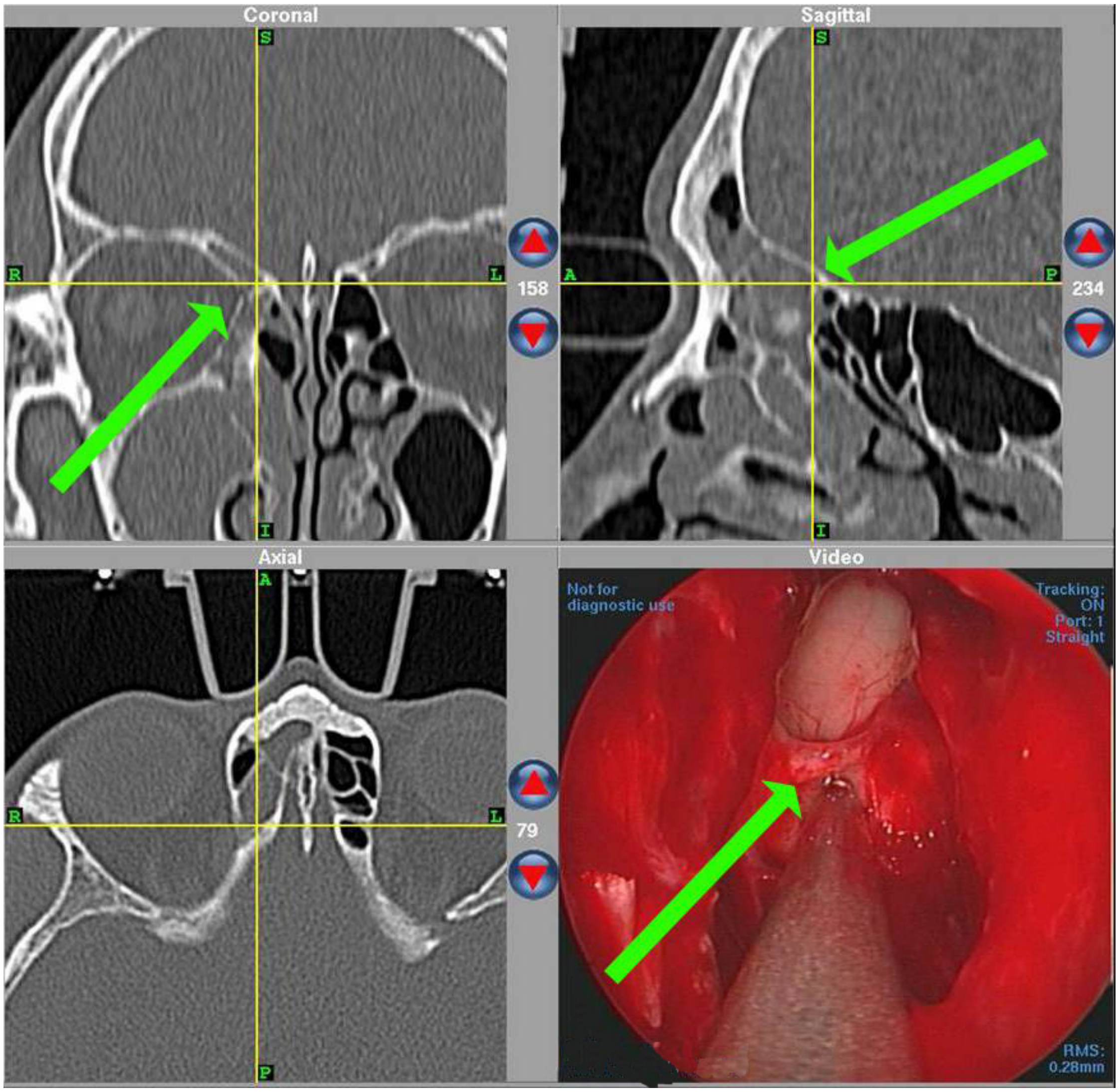


FIG 13

ANTERIOR ETHMOIDAL ARTERY
TRIPLANAR CT IMAGES OPERATIVE VIEW

During Surgical Navigation, the tracker is placed on the right anterior ethmoidal artery. (Green Arrow Operative View).

The frontal sinus opening is seen anterior to the artery.

The artery is seen on the Coronal Scan as the superior medial protrusion of the right orbit (Green Arrow Coronal). On the sagittal scan, the artery is seen (Green Arrow Sagittal) where the Skull Base turns and where an increased bone density is observed. This is most likely due to the bony canal through which the artery passes.

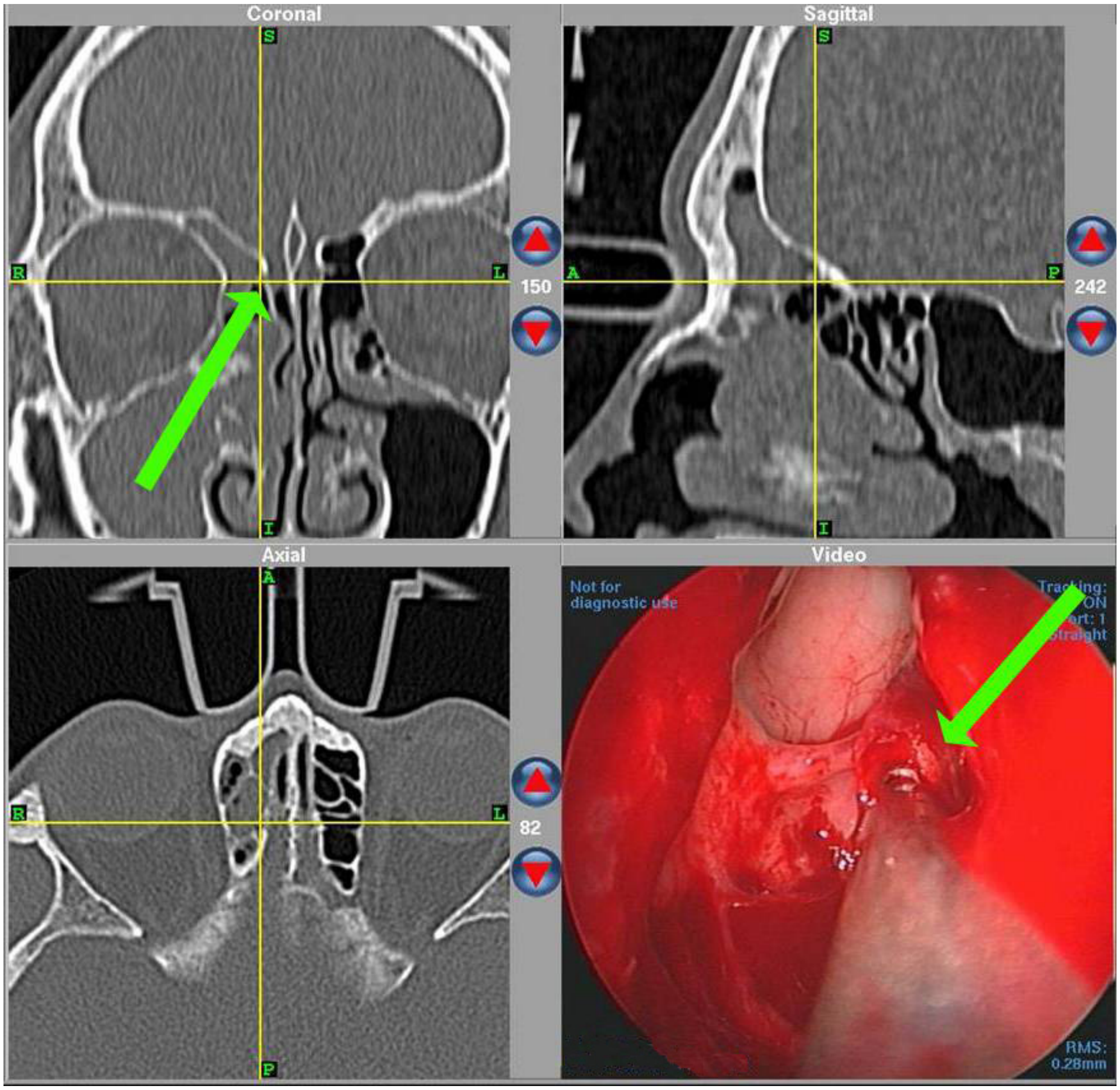


FIG 14

CRIBIFORM PLATE : LATERAL LAMELLA
ETHMOID ROOF CONFIGURATION – KEROS CLASSIFICATION.
TRIPLANAR CT IMAGES OPERATIVE VIEW

The lateral lamella of the cribiform plate (Green Arrow Coronal) where the tracker is placed (Green Arrow Operative View) shows the entry of the anterior ethmoidal artery from medially into the nasal cavity. This is where the skull base is at its thinnest and where it is most susceptible to surgical intrusion causing a cerebrospinal fluid leak.
On the Coronal CT, the *lamina cribrosa* is identified, this patient has two types of ethmoid roof configuration, a Keros Type II on the left (4 – 7 mm) and a Keros Type III on the right (8 – 16 mm).

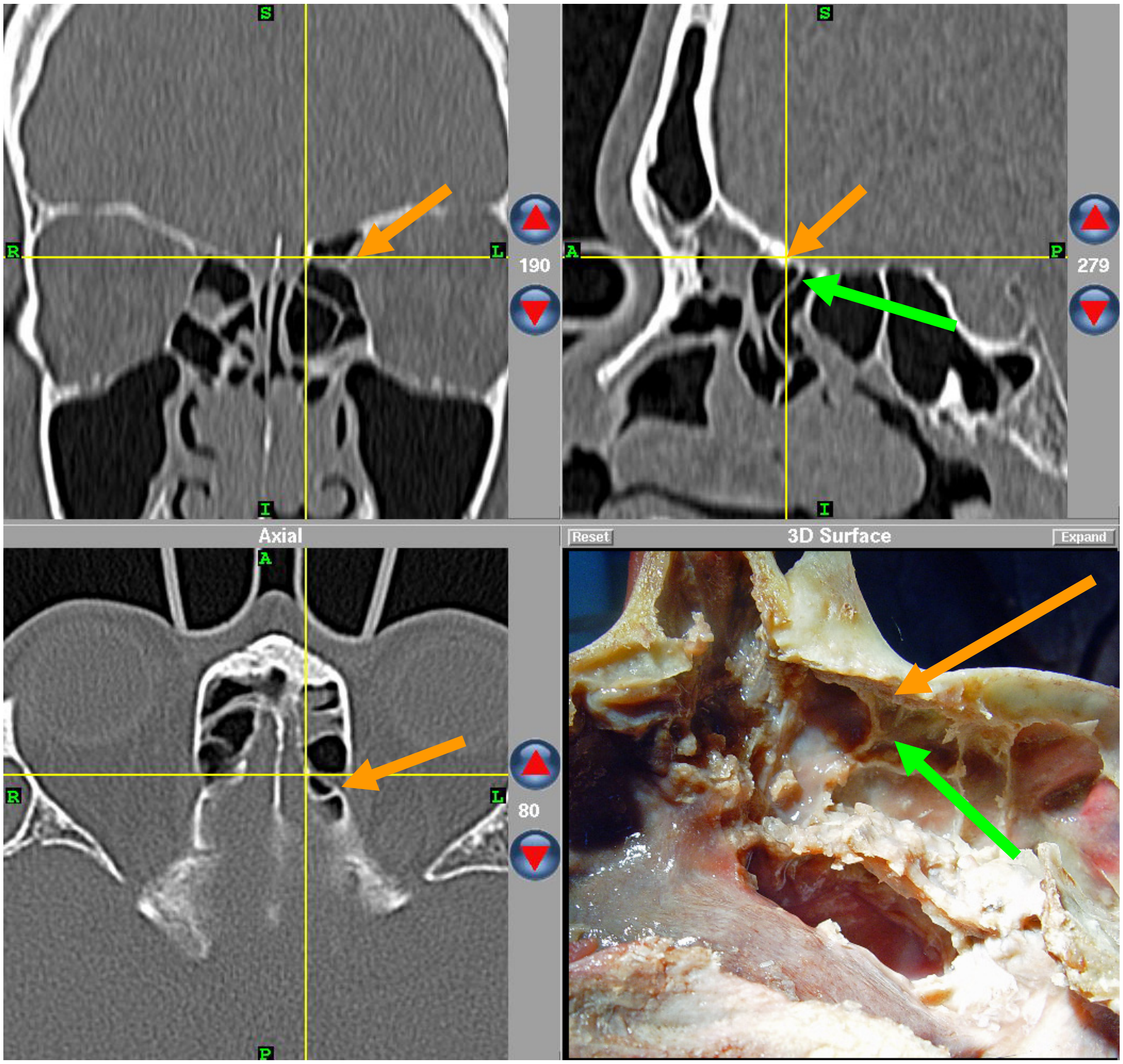


FIG 15

ANTERIOR ETHMOIDAL ARTERY AND THE INTACT ETHMOID BULLA TECHNIQUE
TRIPLANAR CT IMAGES PLANNING VIEW
SAGITTAL CADAVERIC DISSECTION SPECIMEN

The bony thickening along the skull base shows the position of the anterior ethmoidal artery (Orange Arrow Sagittal) and corresponds in this cadaveric dissection specimen to the upward anterior turn of the skull base .(Orange Arrow Cadaveric Specimen)
The anterior ethmoid artery is seen as a medial protrusion from the medial orbital wall (Orange Arrow Coronal) and can be seen to course from posterolateral to anteromedial in the axial scan.(Orange Arrow Axial)
The Ethmoidal Bulla is attached to the skull base posterior to the course of the anterior ethmoidal artery. (Green Arrow Sagittal, Cadaveric Specimen) A safe method of identifying the frontal sinus opening endoscopically has been proposed by Sethi. Surgery in the frontal recess is safe from anterior ethmoid artery injury as long as the ethmoid bulla and its attachment to the skull base is not violated.

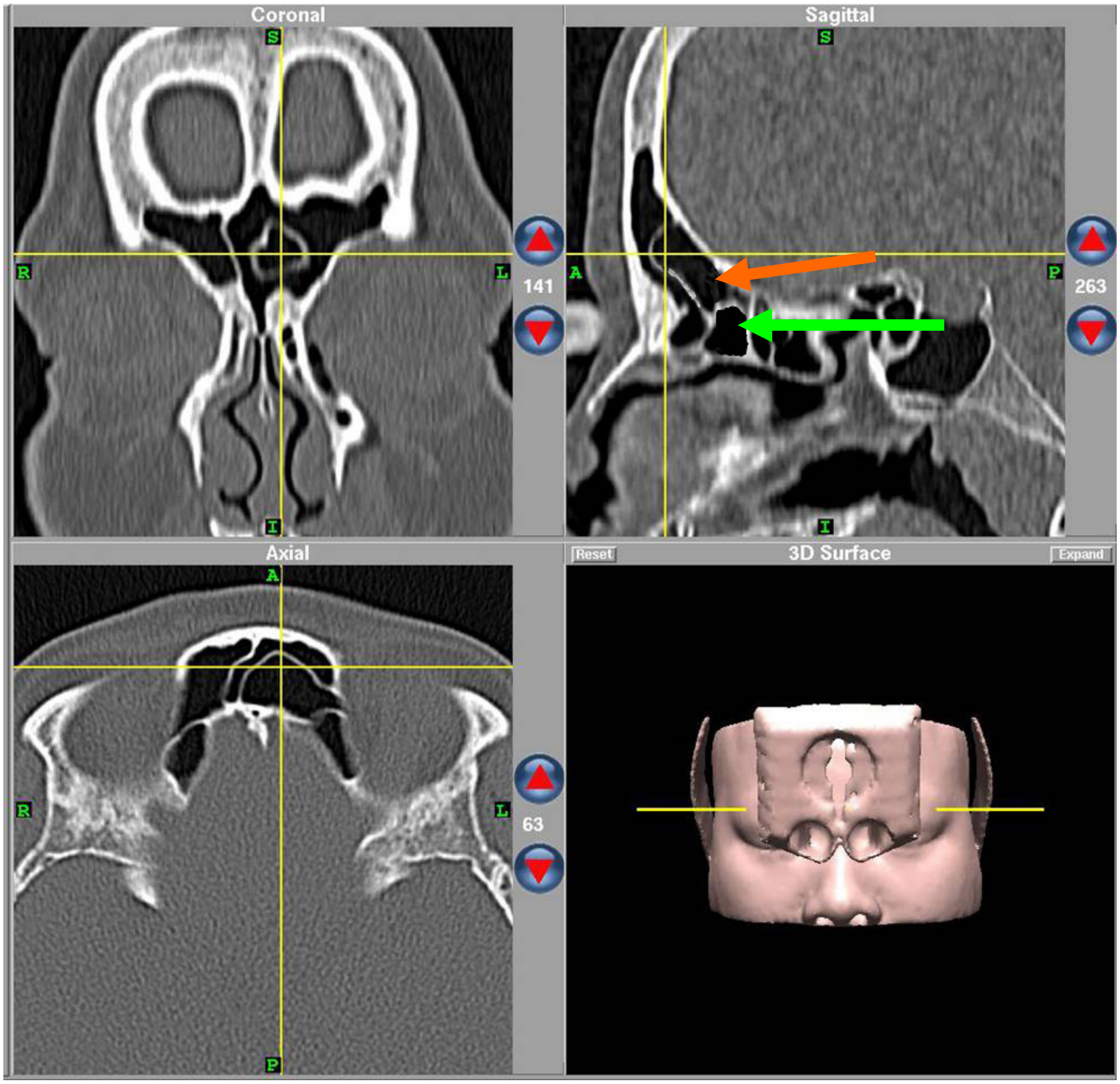


FIG 16

FRONTAL BULLAR CELL [1]
TRIPLANAR CT IMAGES PLANNING VIEW

- Ethmoid cell above ethmoid bulla (Green Arrow Sagittal indicates Ethmoid Bulla)
- Pneumatizes along skull base into frontal sinus from posterior frontal recess
- Posterior wall is anterior cranial fossa skull base (frontal sinus posterior table)
- Anterior border must extend into frontal sinus
- Located behind true frontal sinus pneumatization tract
- May represent pneumatization of the anterior wall of the ethmoidal bulla (bulla lamella)
- May cause convexity in floor of frontal sinus
- Well seen on sagittal CT view (Orange Arrow Sagittal)

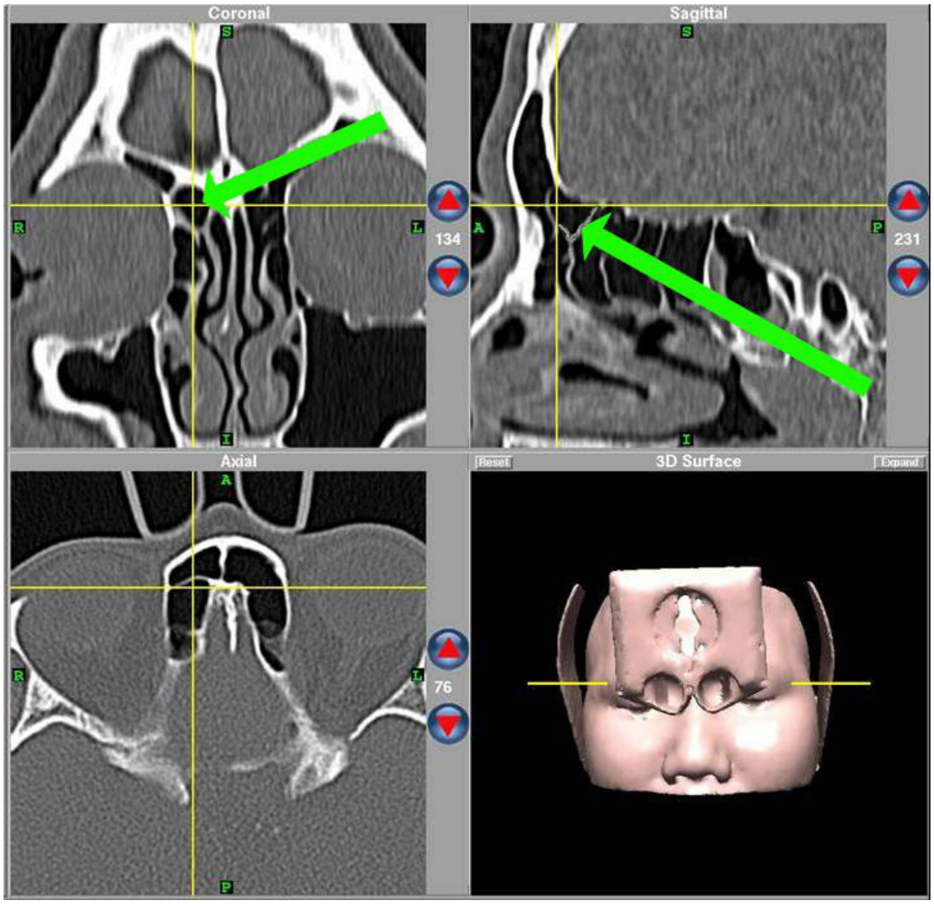


FIG 17

DIFFRENTIATING ANTERIORLY AND POSTERIORLY BASED FRONTAL SINUS CELLS USING TRIPLANAR CT VIEWS.
TRIPLANAR CT IMAGES PLANNING VIEW

The Air Cell shown on Coronal Section could have been interpreted as a Type I Frontal Cell. However, Sagittal View shows that this cell arises posteriorly from above the Ethmoidal Bulla and is thus a Frontal Bulla Cell.

On the Sagittal view, the insertion of the lamella of the frontal bulla cell is seen to reach far anteriorly , the frontal recess becomes narrowed from the posterior. This results in a tubular appearance which is the reason the narrowed recess came to be known, albeit incorrectly, as the nasofrontal duct.

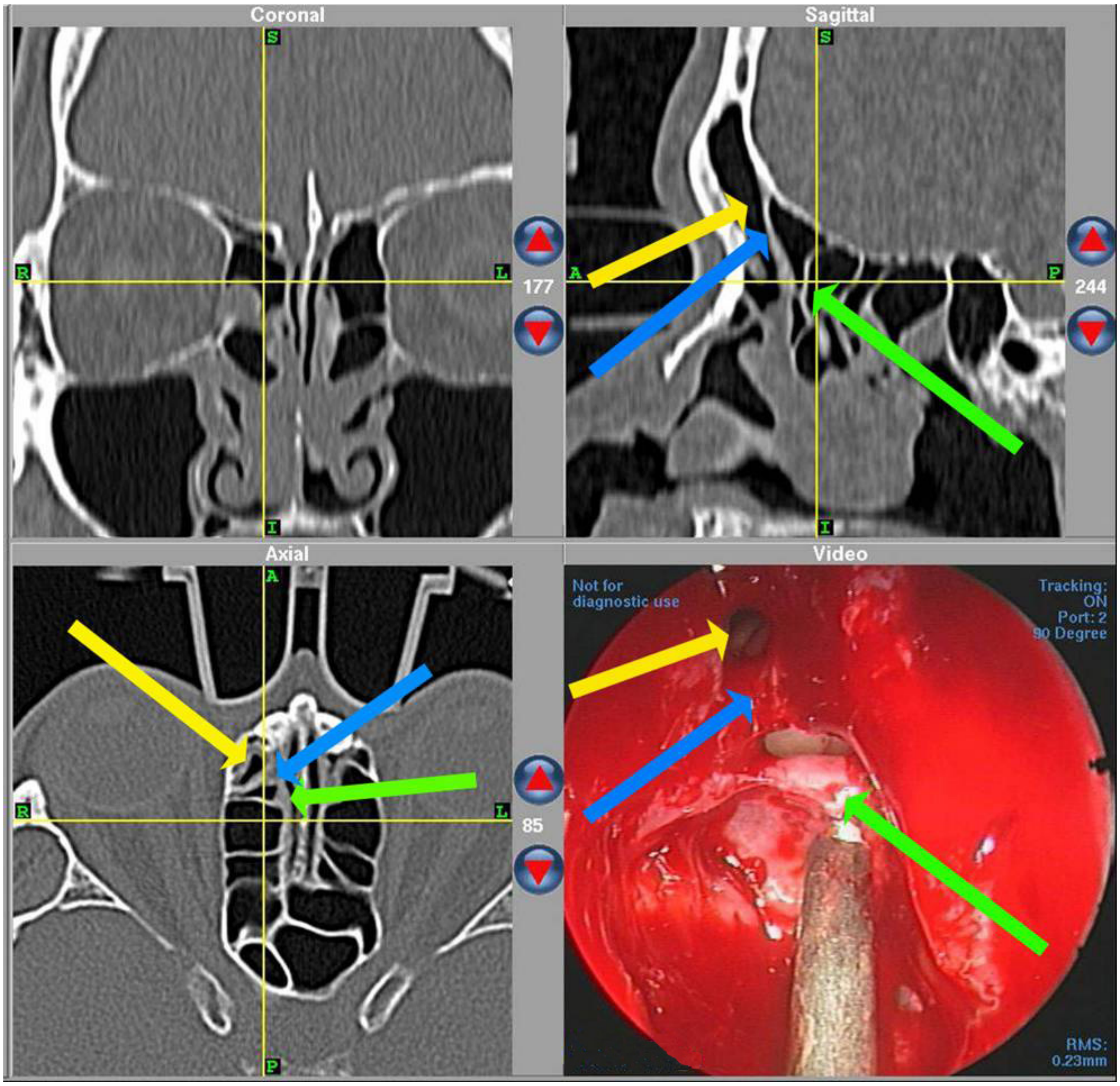


FIG 18

DEMONSTRATING A SYSTEMIC APPROACH INTO THE FRONTAL SINUS REMOVING THE ANTERIOR LAMELLA OF THE FRONTAL BULLA CELL TRIPLANAR CT IMAGES OPERATIVE VIEW

The Lamella of the Frontal Bulla Cell and the Ethmoid Bulla are well seen in this Surgical Navigation series.
The tracker is placed at the remnant lamella of the ethmoid bulla (Green Arrow – all sections). The lamella of the Frontal Bulla Cell is seen on the Sagittal and Axial Views and correspondingly on the Intra-operative View. (Blue Arrows). The opening of the Frontal Sinus is seen anterior to the lamella of the Frontal Bulla Cell. (Yellow Arrow)

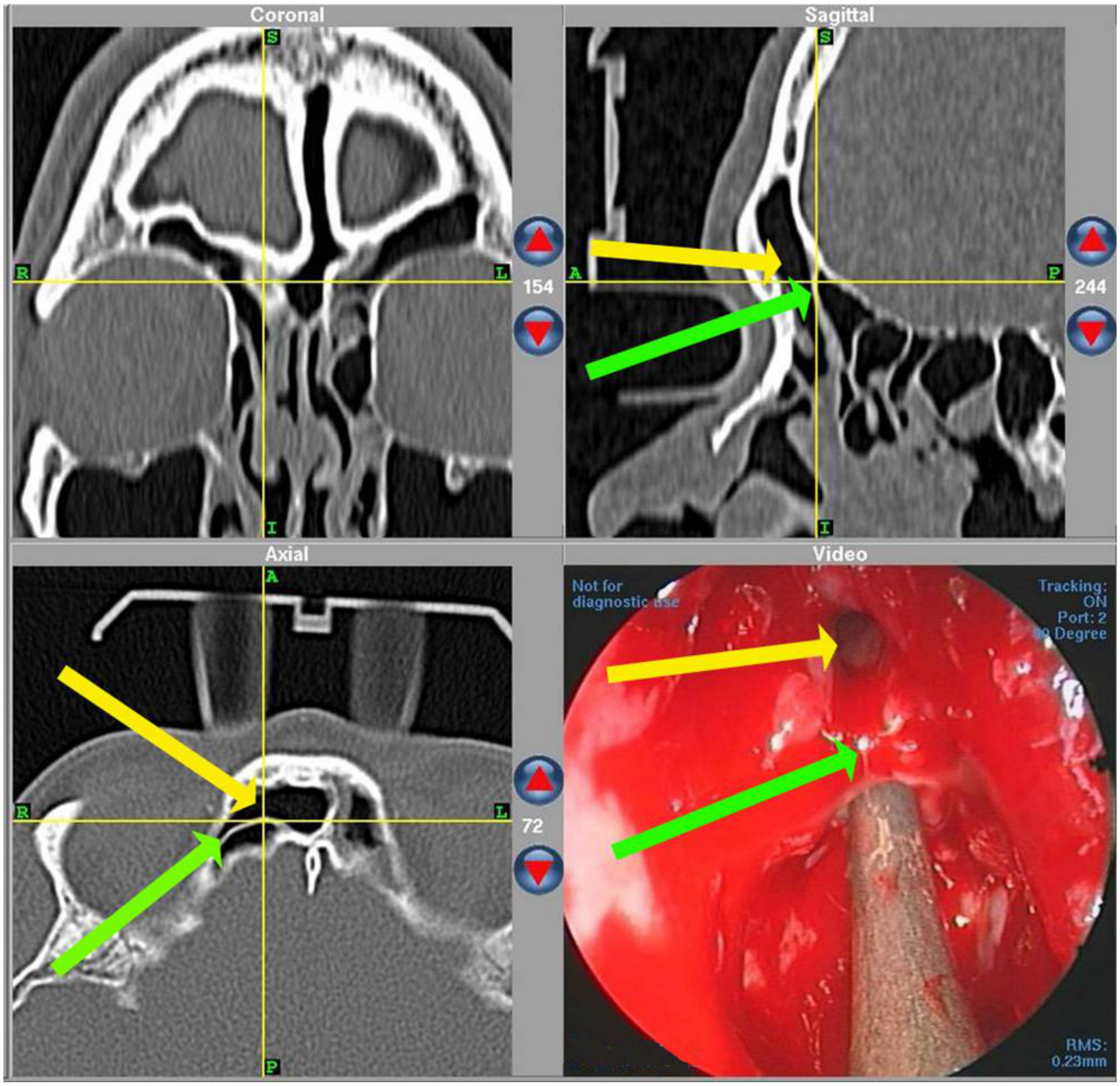


FIG 19

DEMONSTRATING A SYSTEMIC APPROACH INTO THE FRONTAL SINUS REMOVING THE ANTERIOR LAMELLA OF THE FRONTAL BULLA CELL TRIPLANAR CT IMAGES OPERATIVE VIEW

The navigation probe is placed at posterior table of the frontal sinus, posterior to the lamella of the frontal bulla cell (Green Arrow –All Views)
The frontal sinus is indicated by the Yellow Arrow –All Views.

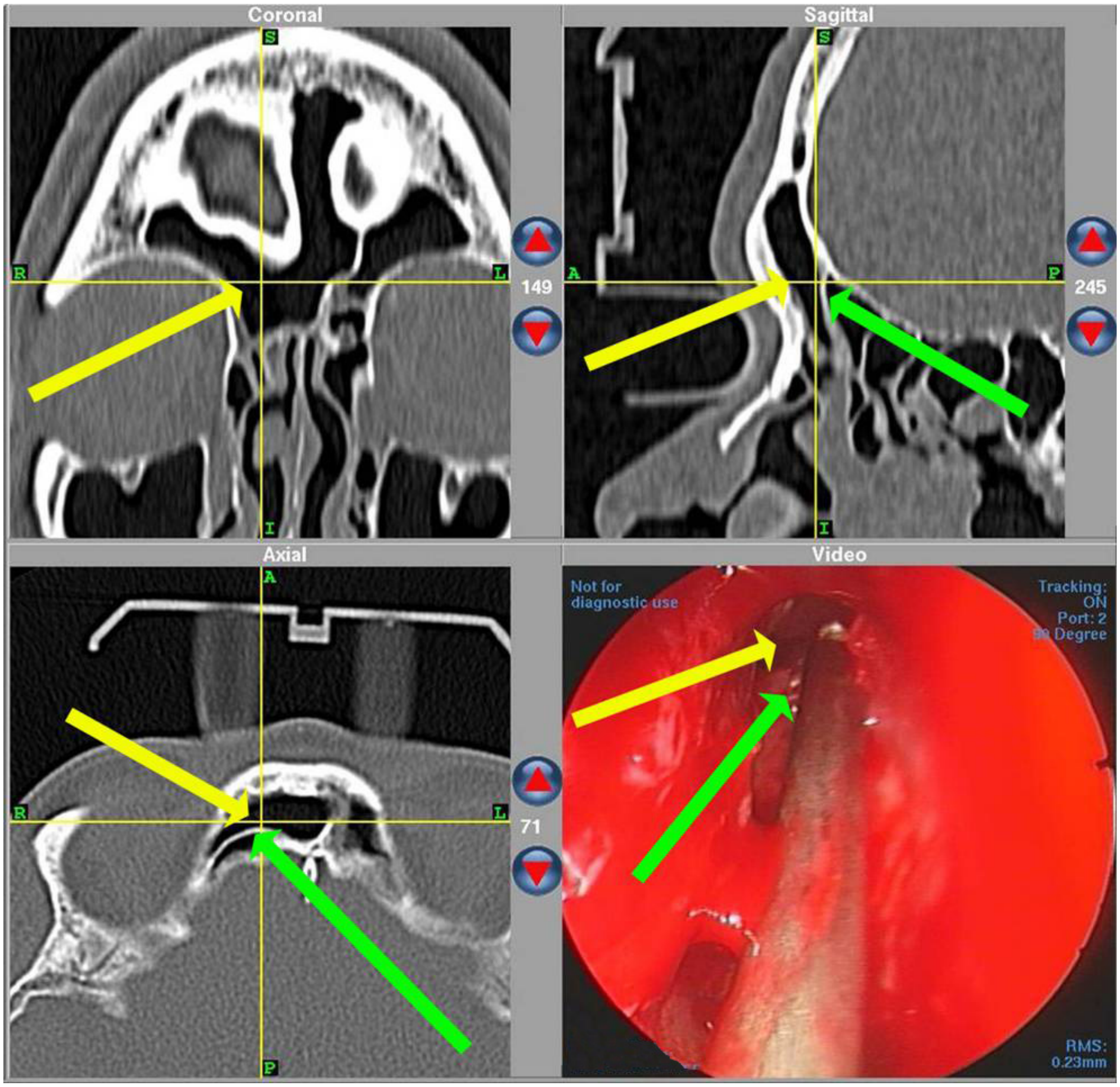


FIG 20

DEMONSTRATING A SYSTEMIC APPROACH INTO THE FRONTAL SINUS REMOVING THE ANTERIOR LAMELLA OF THE FRONTAL BULLA CELL TRIPLANAR CT IMAGES OPERATIVE VIEW

The navigation probe is placed into the frontal sinus anterior to the lamella of the Frontal Bulla Cell (Green Arrow All Views) after this lamella is removed.
The frontal sinus is indicated by the Yellow Arrow in all views.

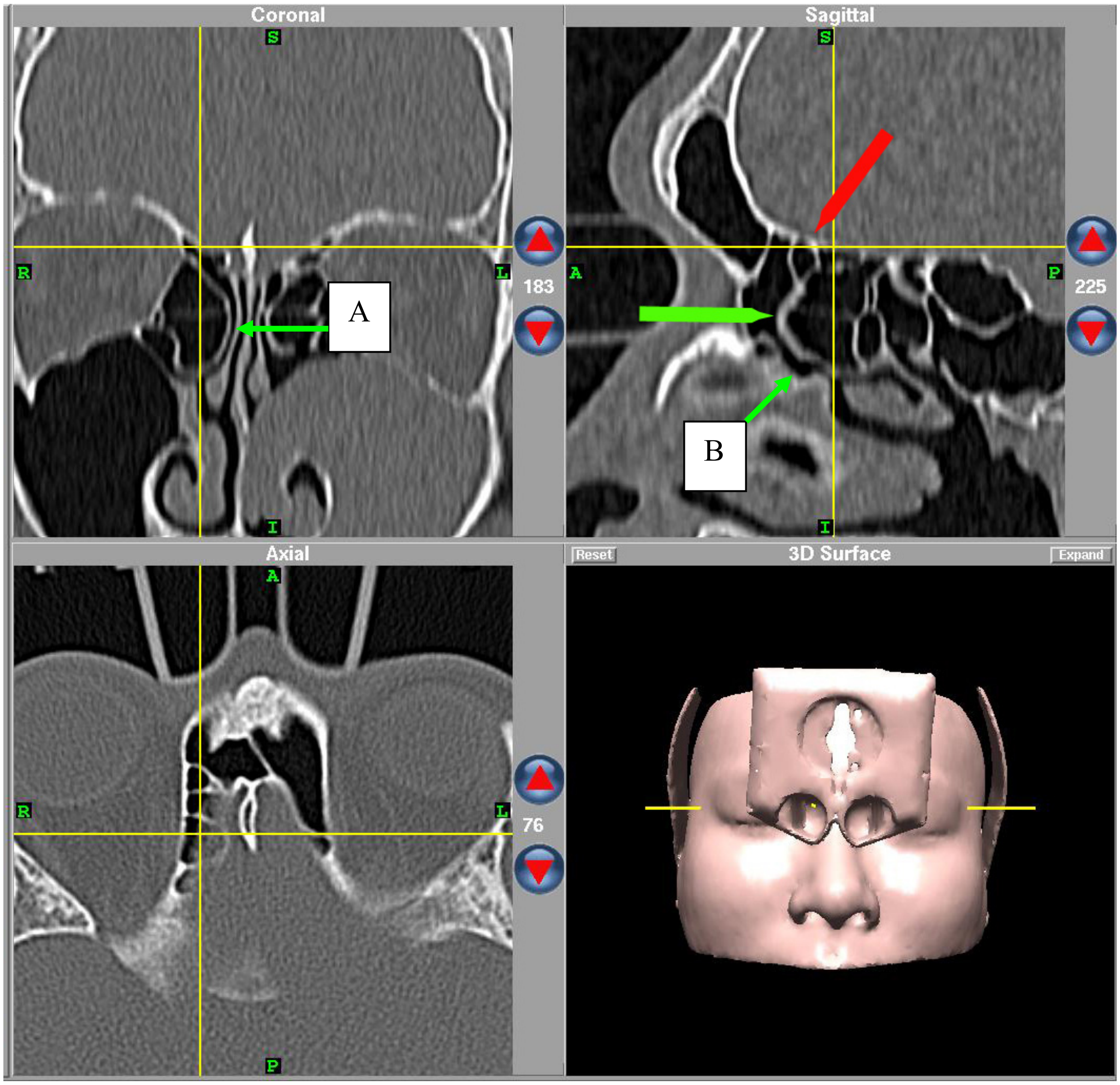


FIG 21

SUPRABULLAR CELL [1]
TRIPLANAR CT IMAGES PLANNING VIEW

- Ethmoid cell (Red Arrow Sagittal) above Ethmoid bulla (Green Arrow Sagittal)
- Superior wall is anterior cranial fossa skull base
- Anterior border does not extend into frontal sinus
- May represent pneumatization of the anterior wall of the ethmoidal bulla (bulla lamella)
- Well seen on sagittal CT view
- Bears close resemblance to the suprabullar recess (CT view alone is inadequate to distinguish between the suprabullar cell and the suprabullar recess.)

The *hiatus semilunaris superior* (A) is identified on the coronal view and the *hiatus semilunaris inferior* (B) is identified on the sagittal view.

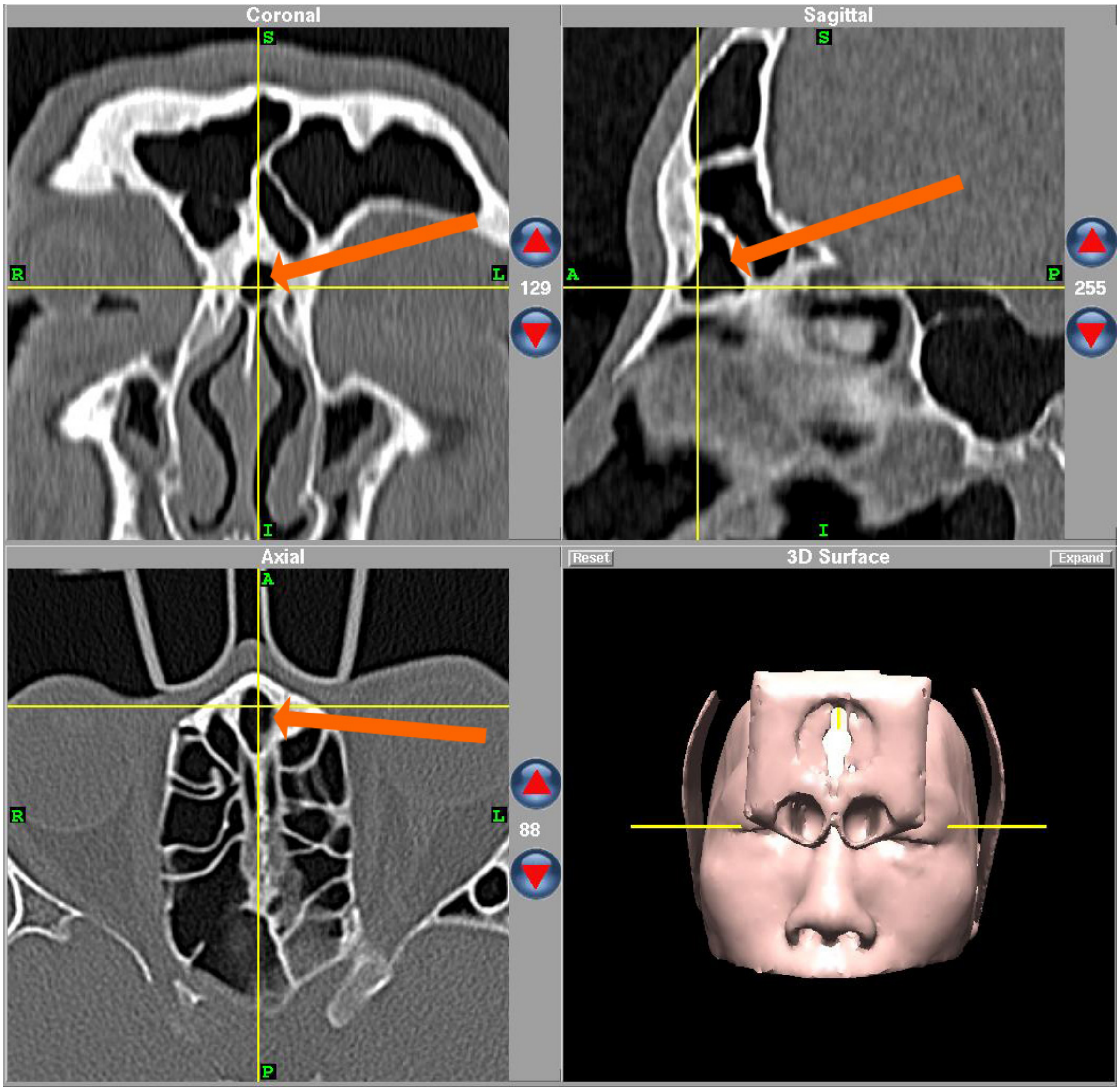


FIG 22

INTER FRONTAL SINUS SEPTAL CELL [1]
TRIPLANAR CT IMAGES PLANNING VIEW

- Pneumatization of the frontal sinus septum
- Drains into one frontal recess
- Associated with pneumatized *crista galli*
- Well seen on axial and coronal sinus CT view

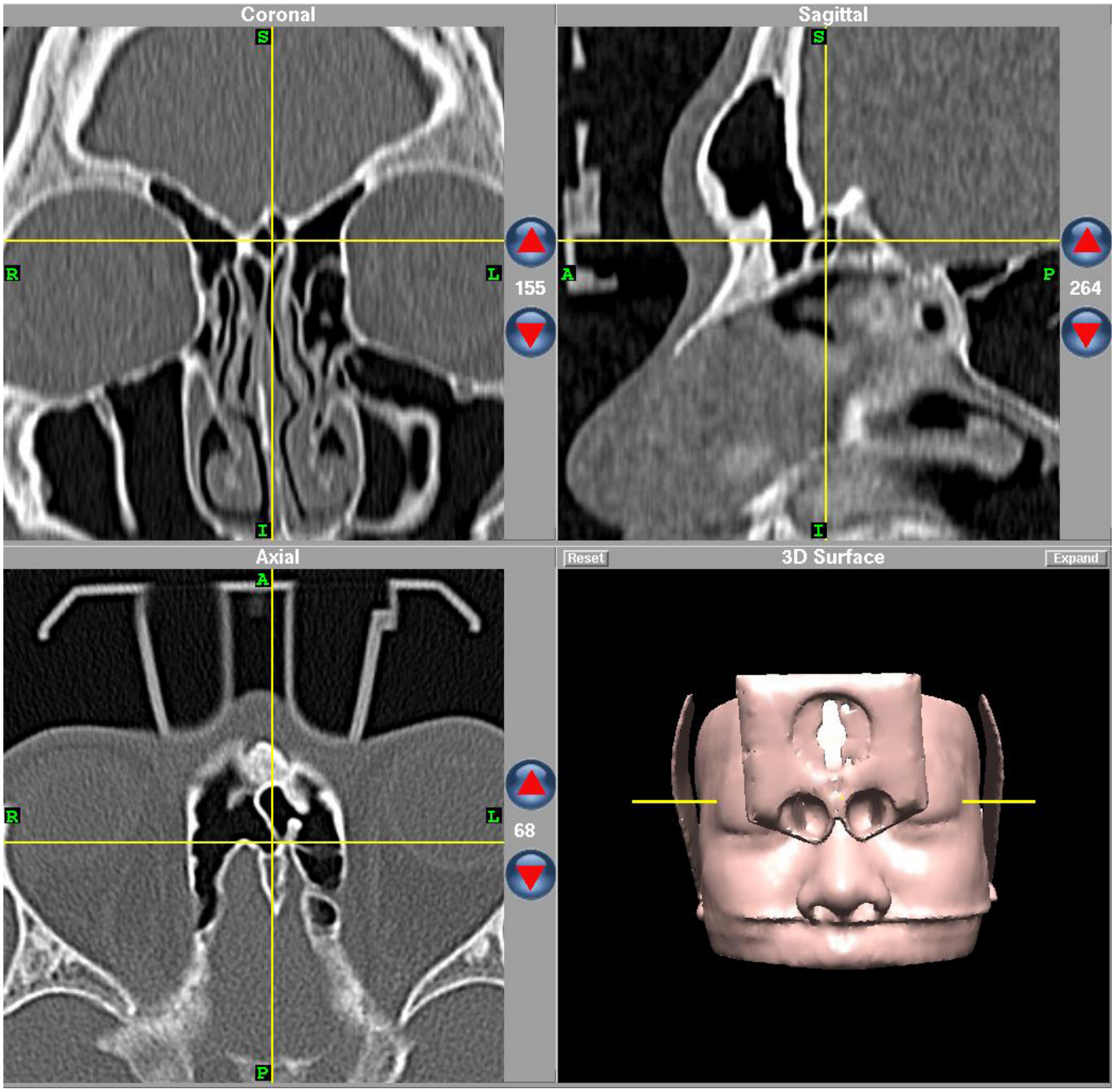


FIG 23

**IDENTIFICATION OF AN INTER FRONTAL SINUS SEPTAL CELL.
TRIPLANAR CT IMAGES PLANNING VIEW**

Coronal and Sagittal views would suggest an interfrontal sinus septal cell.
Axial view on however shows that the area indicated is the right frontal sinus located posterior to an S shaped inter frontal sinus septum and that an inter frontal sinus septal cell does not exist.

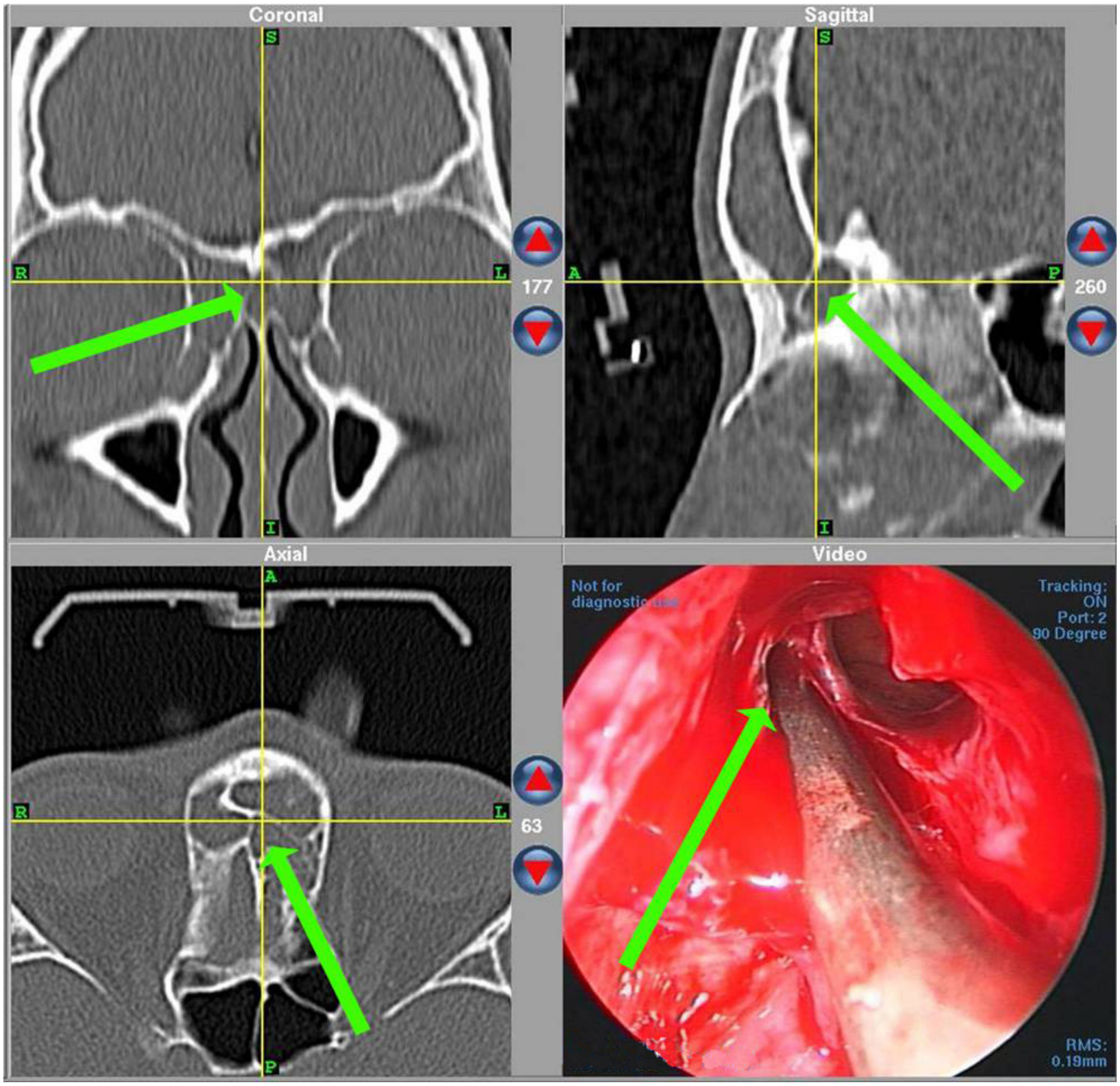


FIG 24

INTER FRONTAL SINUS SEPTAL CELL [1]
TRIPLANAR CT IMAGES OPERATIVE VIEW

During Surgical Navigation, the tracker is placed into the Inter Frontal Sinus Septal Cell (Green Arrow All Views). It is clearly shown to be medial to the opening of the frontal sinus and its intervening septum should be removed once frontal recess surgery is embarked upon so that the frontal recess may be opened widely.

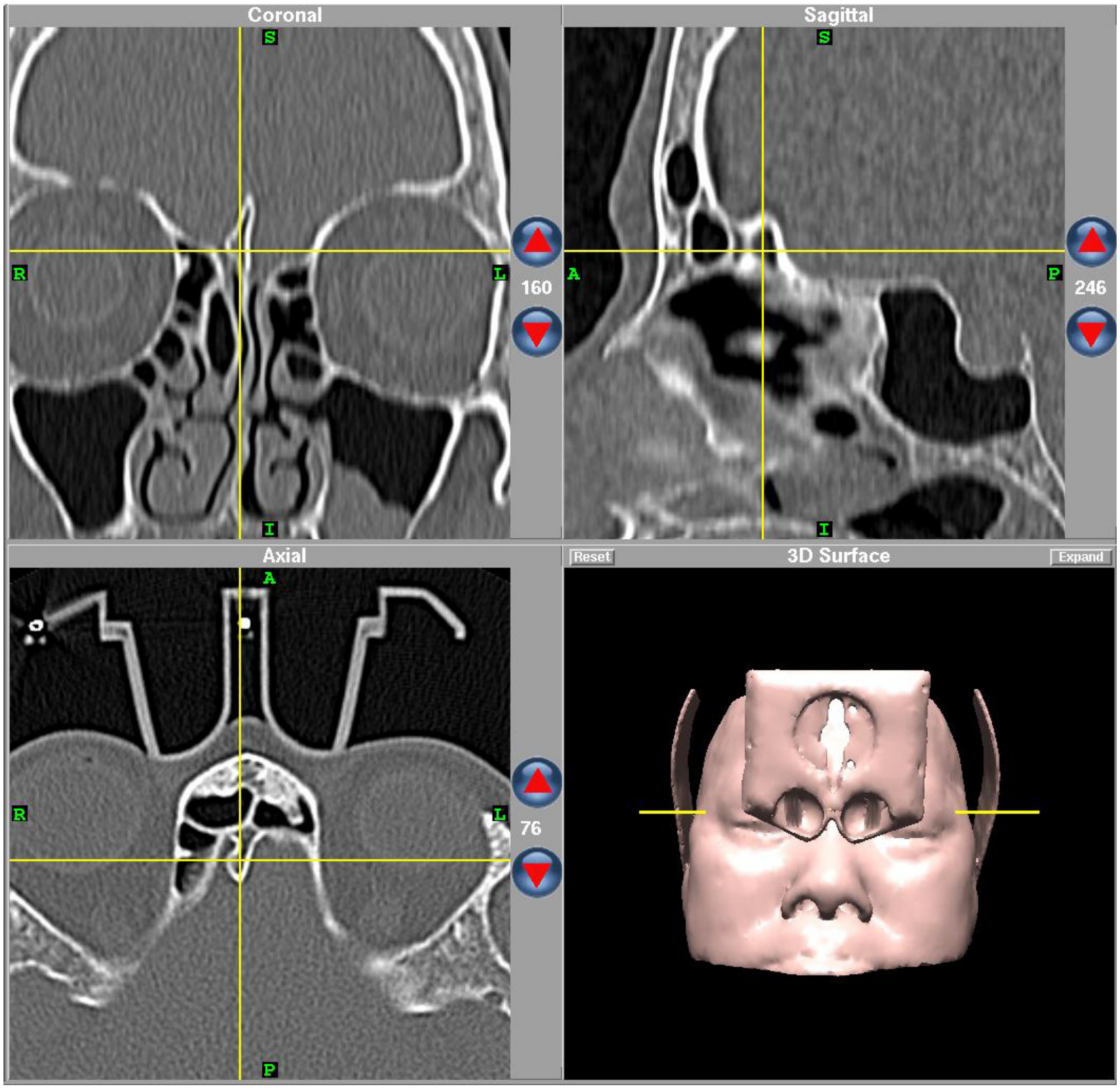


FIG 25

PNEUMATISED *CRISTA GALLI* [1]
TRIPLANAR CT IMAGES PLANNING VIEW

Pneumatized *Crista Galli* indicated by the confluence of the crosshairs in all views. It is often associated with an Inter Frontal Sinus Septal Cell. It usually drains into the posterior aspect of the frontal sinus. If it did not have a drainage route, it would form a mucocele of the crista galli which is a rare and yet to be reported entity.
Although it is theoretically possible during surgery for surgical instruments to enter into this pneumatized *crista galli* and beyond into the brain, its relative inaccessibility due to its position high and within the frontal sinus makes this an uncommon event that has yet to be reported..

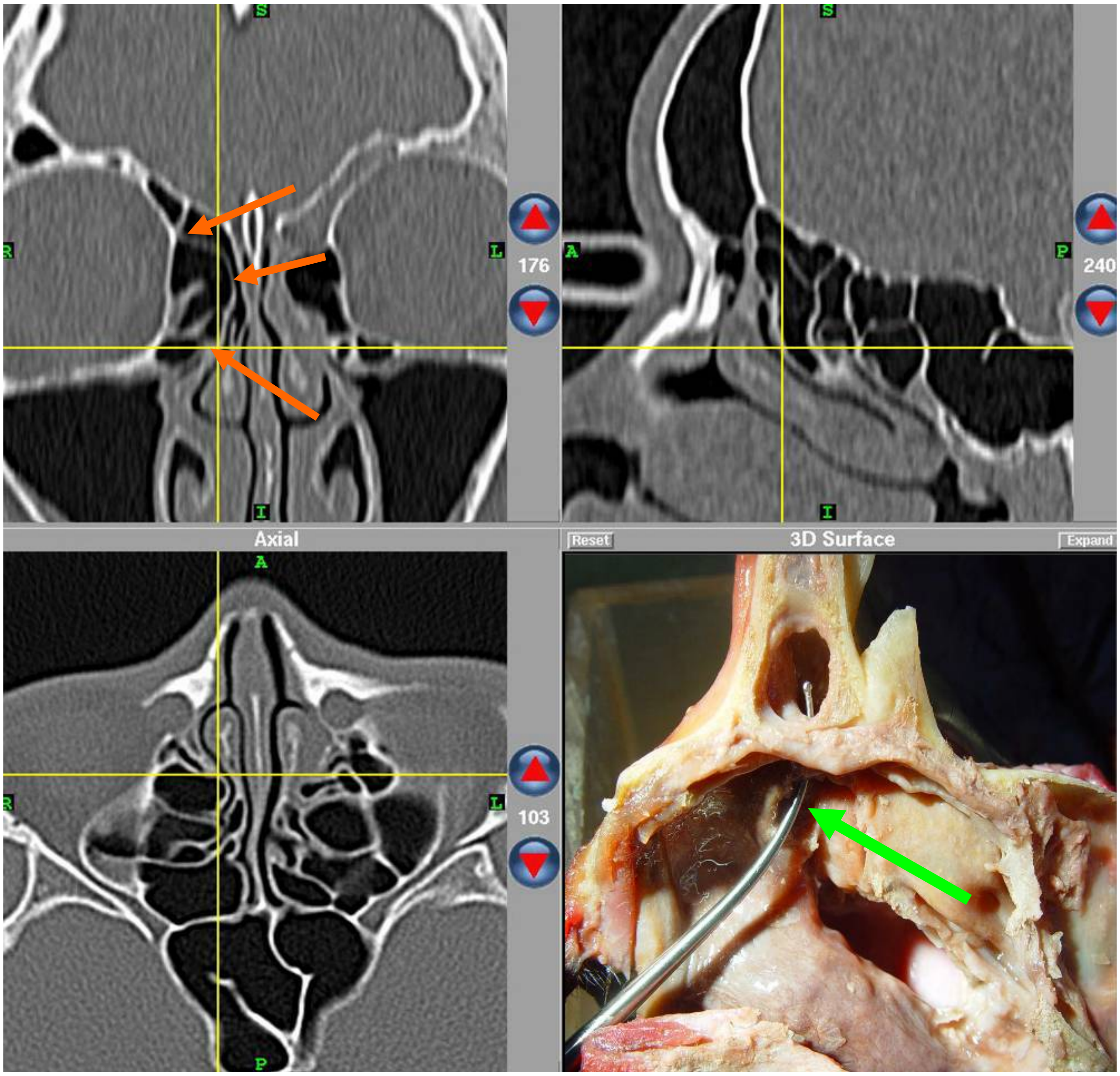


FIG 26

RECESSUS TERMINALIS [1]
TRIPLANAR CT IMAGES PLANNING VIEW
CADAVERIC SPECIMEN VIEW

- The superior uncinate process attaches laterally to the orbit, below internal frontal ostium (Orange Arrows Coronal)
- Frontal sinus drains directly into middle meatus
- Often associated with *agger nasi* cell
- . Well seen on coronal sinus CT view

In the cadaveric specimen, the uncinate process has been removed. Its superior attachment is on to the lateral aspect of the orbital wall thus allowing the bent probe to be passed without obstruction into the frontal sinus from the infundibulum. The ethmoid bulla (GreenArrow) has been partially opened, the probe is slipped up the *hiatus semilunaris superior* into the frontal sinus.

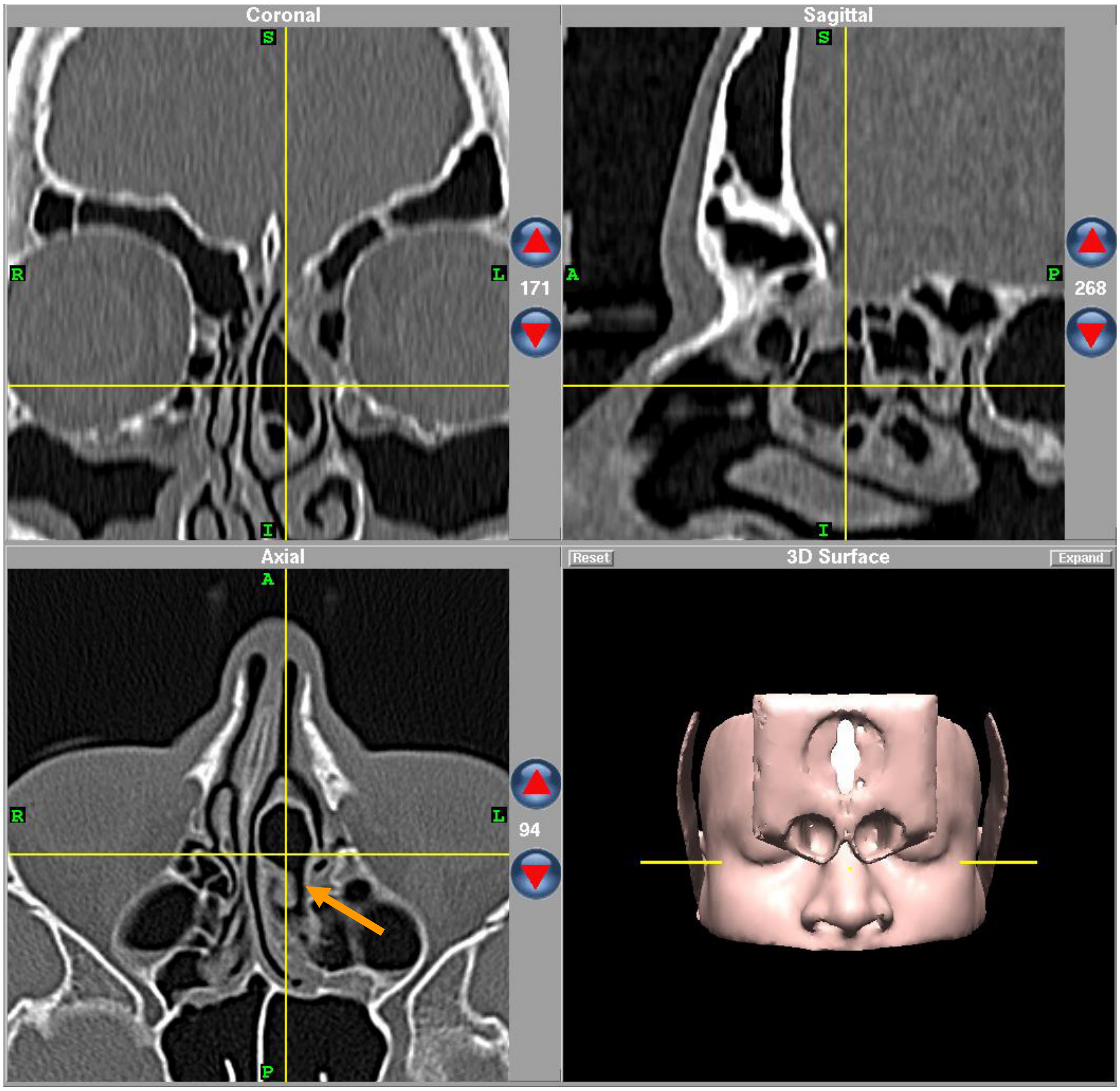


FIG 28

CONCHA BULLOSA [2]
TRIPLANAR CT IMAGES PLANNING VIEW

Concha Bullosa is pneumatization of the middle turbinate (Cross Hairs Coronal and Axial Views) and this air cell drains posteriorly (Orange Arrow Axial). The amount of pneumatization occurs over a spectrum from being barely discernible to being large enough to contribute to pathological obstruction. It is clinically significant only when it obstructs the infundibulum causing sinusitis. Pre-operative recognition alerts the surgeon to plan for resection of the lateral lamella of the *concha bullosa* enhancing endoscopic view, allowing easy passage of instruments and reducing post-operative obstruction of the infundibulum.

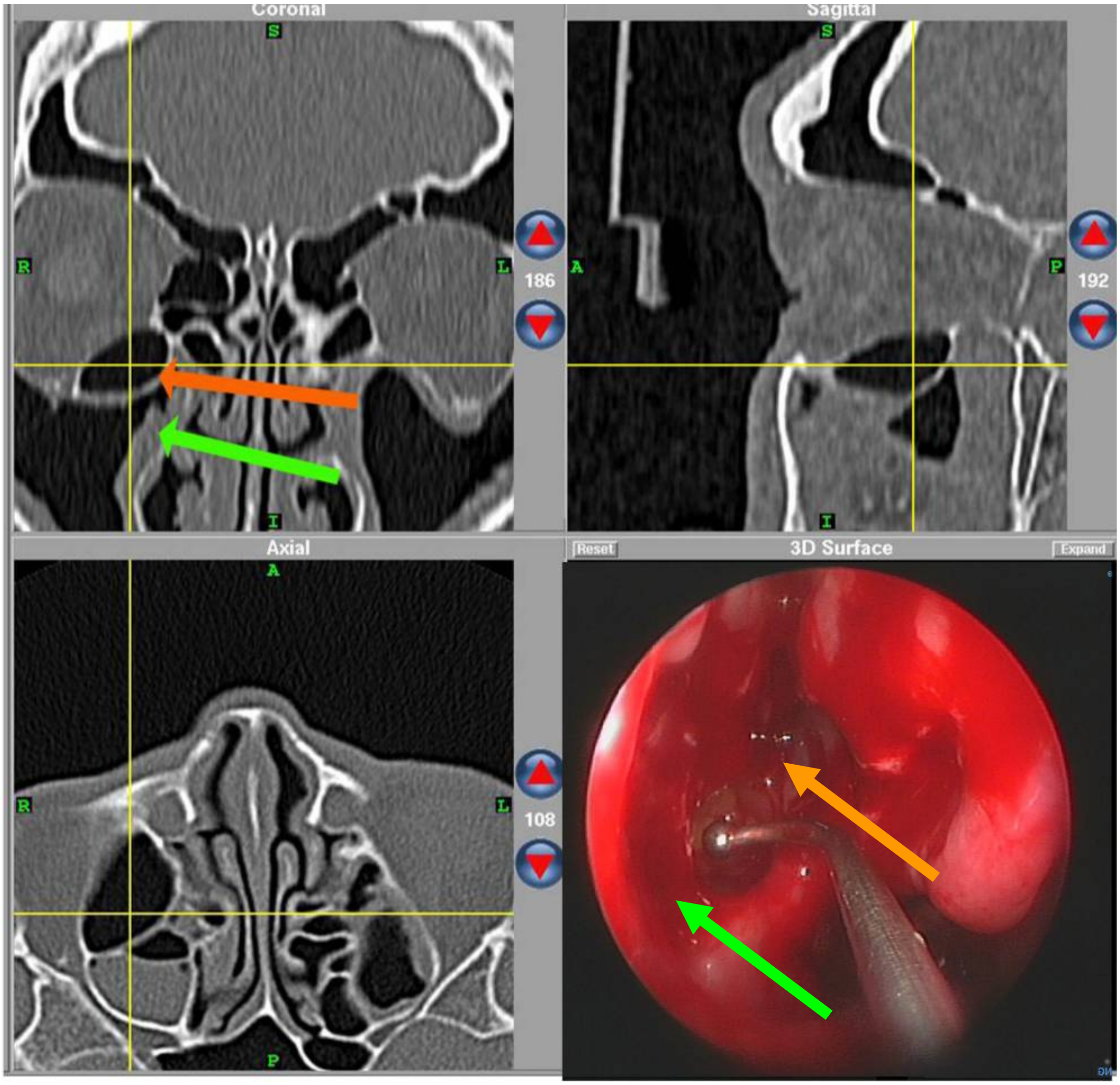


FIG 29

HALLER CELLS [2]
TRIPLANAR CT IMAGES PLANNING VIEW
ENDOSCOPIC VIEW DURING SURGERY

The Haller cell (Orange Arrow Coronal) may impede drainage of the sinus ostium (Green Arrow Coronal). If a surgeon fails to recognize the Haller cell, he may open into the Haller cell from medially and presume that the sinus ostium has been opened. This will contribute to inadequate drainage of the maxillary sinus and predispose to a recurrence of sinusitis.
In the Endoscopic Operative View the sinus ostium (Green Arrow Coronal) is anterior to and made narrow by the anterior and medial walls of the large Haller cell which has been partially opened. (Orange Arrow Coronal)

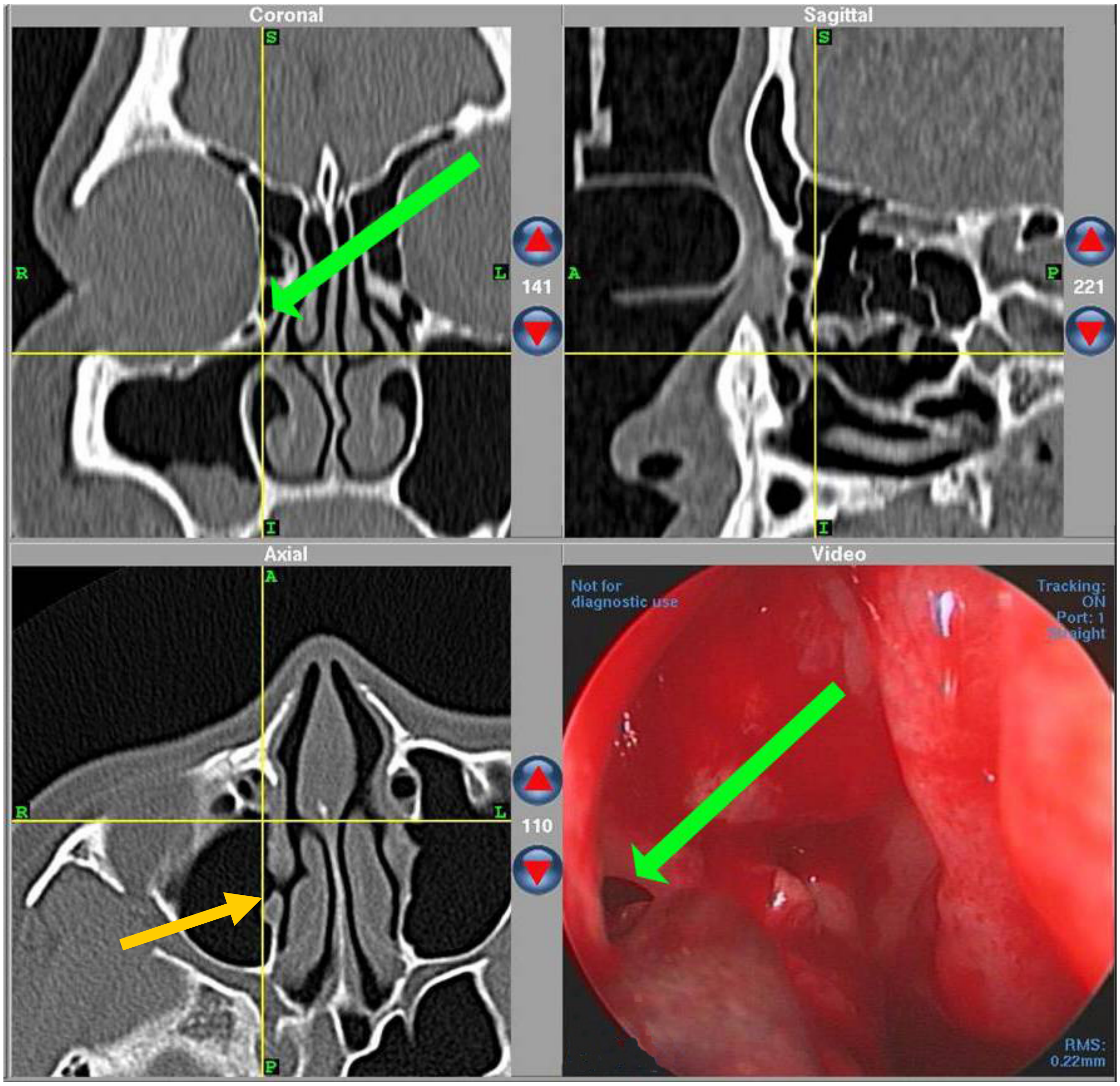


FIG 30

A SMALL HALLER CELL , SECONDARY FONTANELLE.
TRIPLANAR CT IMAGES OPERATIVE VIEW

The natural sinus ostium cannot be viewed with the endoscope without first removal of the uncinate process. The natural sinus ostium is seen on Surgical Navigation after removal of the uncinate process. (Green Arrow Operative View) where the tracker is now placed. A small Haller cell is seen (Green Arrow – Coronal), removal of this Haller cell will allow better drainage of the sinus ostium.
The maxillary infundibulum is seen on the Coronal View between the Haller cell and the uncinate process. A secondary fontanelle or accessory ostium is seen (Orange Arrow Axial). This secondary fontanelle , occurring posterior to the sinus ostium can often be viewed with an endoscope without first removal of the uncinate process.
The anterior fontanelle is inferior and anterior to the uncinate process; the posterior fontanelle is superior and posterior to the part of the uncinate process that fuses with the medial wall of the maxillary sinus.

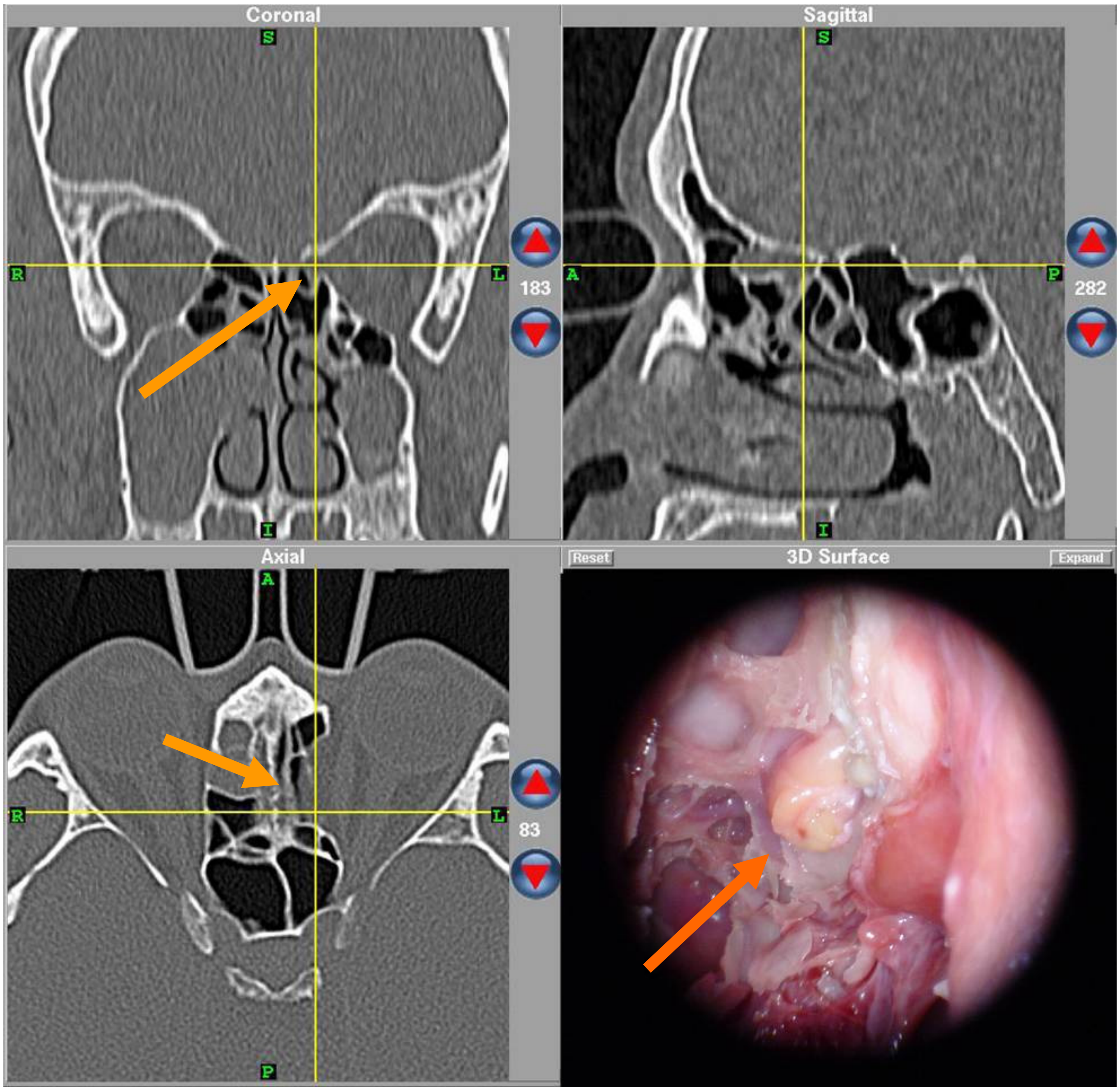


FIG 31

DEHISCENCE OF LAMINA PAPYRICEA
TRIPLANAR CT IMAGES PLANNING VIEW
ENDOSCOPIC VIEW OF CADAVERIC SPECIMEN

It is important to note for natural dehiscence of the lamina papyricea, orbital fat may easily protrude into the ethmoid sinus during surgery following minor trauma and damage to the underlying orbital periosteum. (Orange Arrow Coronal , Axial , Endoscopic Views). Such dehiscence predispose to orbital content injury if unrecognized during surgery.

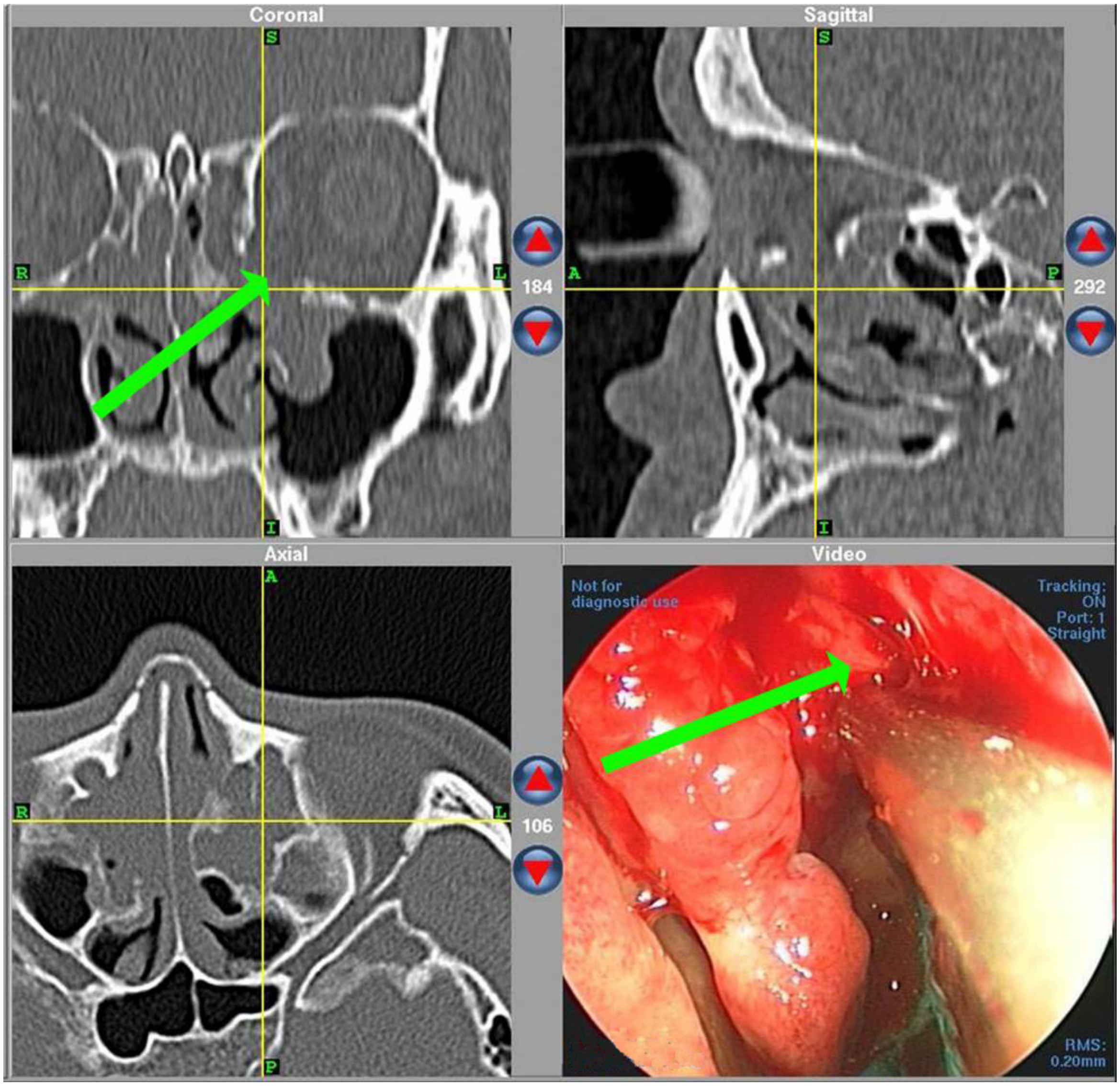


FIG 32

DEHISCENCE OF THE LAMINA PAPYRICEA
TRIPLANAR CT IMAGES OPERATIVE VIEW

At Surgical Navigation, the break at the lamina papyricea with extrusion of orbital fat is noted with the tracker placed at the dehiscence. (Green Arrow, Coronal, Operative View). This is a very important feature to note, as powered instruments such as micro debriders that cut and ablate are now frequently used in endoscopic sinus surgery. With an oscillating speed of 3000 rounds per minute ,a delay of 4 seconds for the surgeon to realize something is amiss will allow the microdebrider to suck and possibly cut orbital contents 200 times.

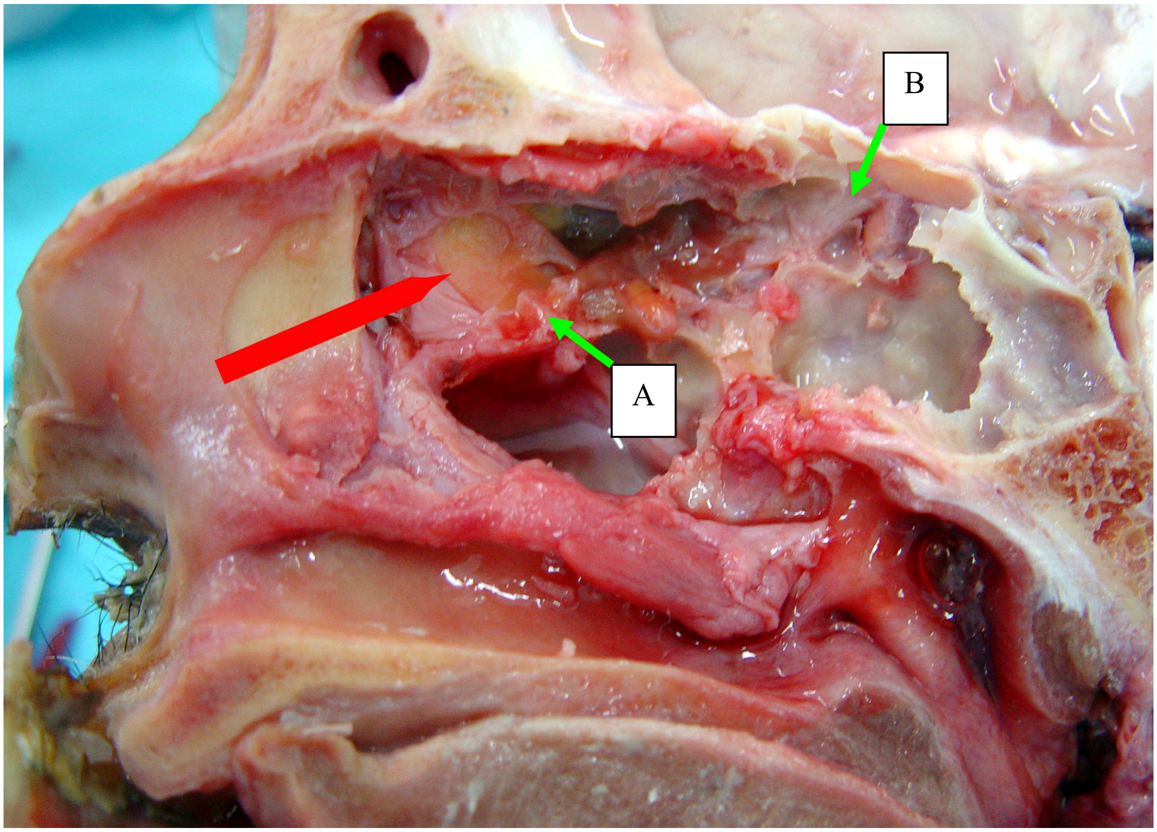


FIG 33

EXPOSURE OF ORBITAL FAT THROUGH THE LAMINA PAPYRICEA SAGITTAL CADAVERIC DISSECTION SPECIMEN

Orbital fat is shown in this cadaveric dissection (Red Arrow) where the *lamina papyricea* has been removed. This site above the sinus ostium is a common place for natural dehiscence of the *lamina papyricea*.
The bony ledge (A) fusing the lamina papyricea with the roof of the maxillary is difficult to remove endoscopically and limits the success of orbital fat decompression in thyrotoxic opthalmopathy from the medial and inferior aspect alone.

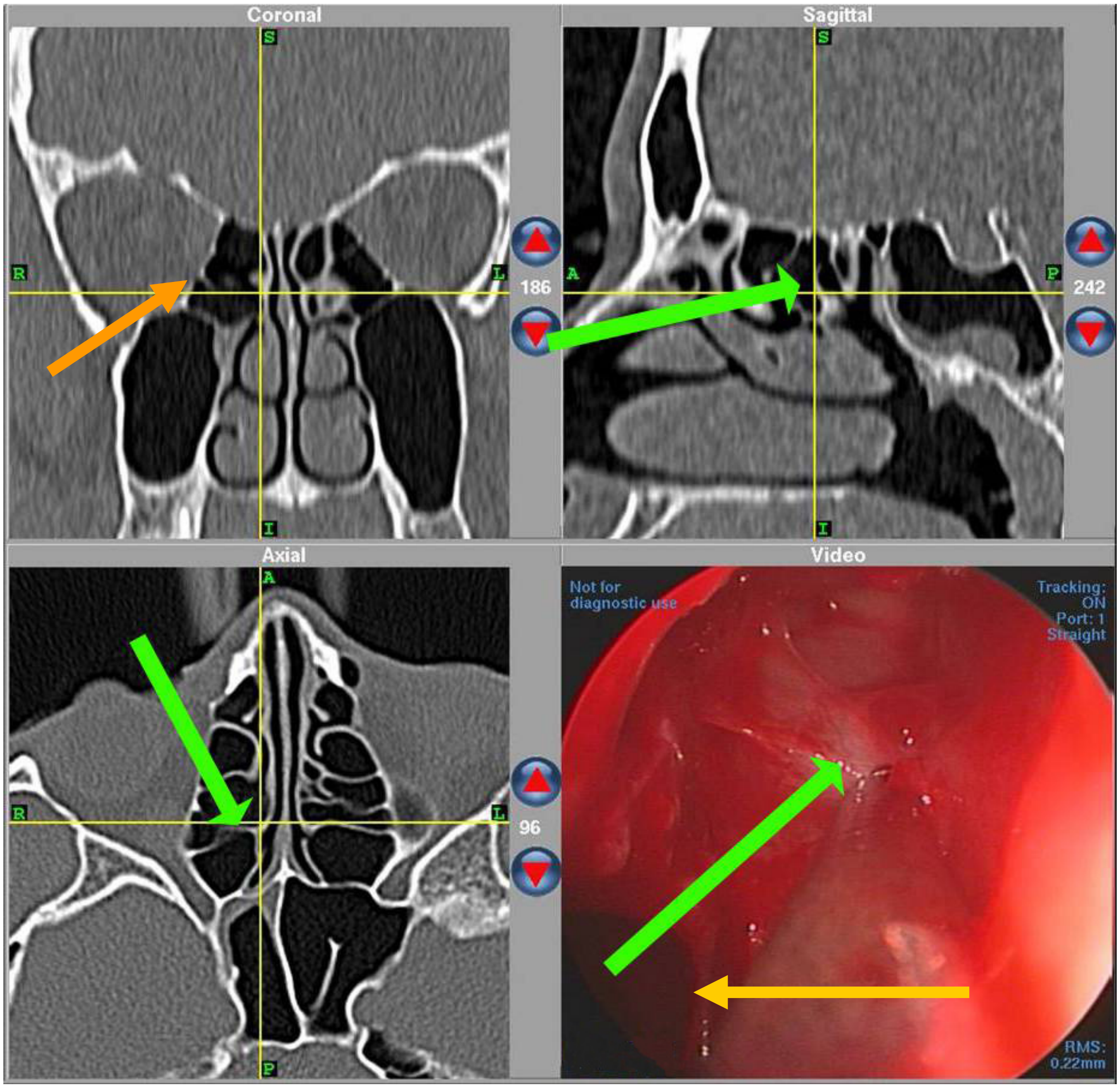


FIG 34

BASAL LAMELLA OF THE MIDDLE TURBINATE
TRIPLANAR CT IMAGES OPERATIVE VIEW

The basal lamella, which is a part of the middle turbinate, separates the anterior and posterior ethmoid air cells and is recognized on the coronal section by the turn of the attachment of the middle turbinate from the skull base to the lamina papyricea. (Orange Arrow Coronal).

The tracker is placed at the basal lamella (Green Arrow Operative View) just above the newly created widely opened sinus ostium, (Orange Arrow Operative View). The basal lamella is best viewed on the axial and sagittal views. (Green Arrow Sagittal, Axial).

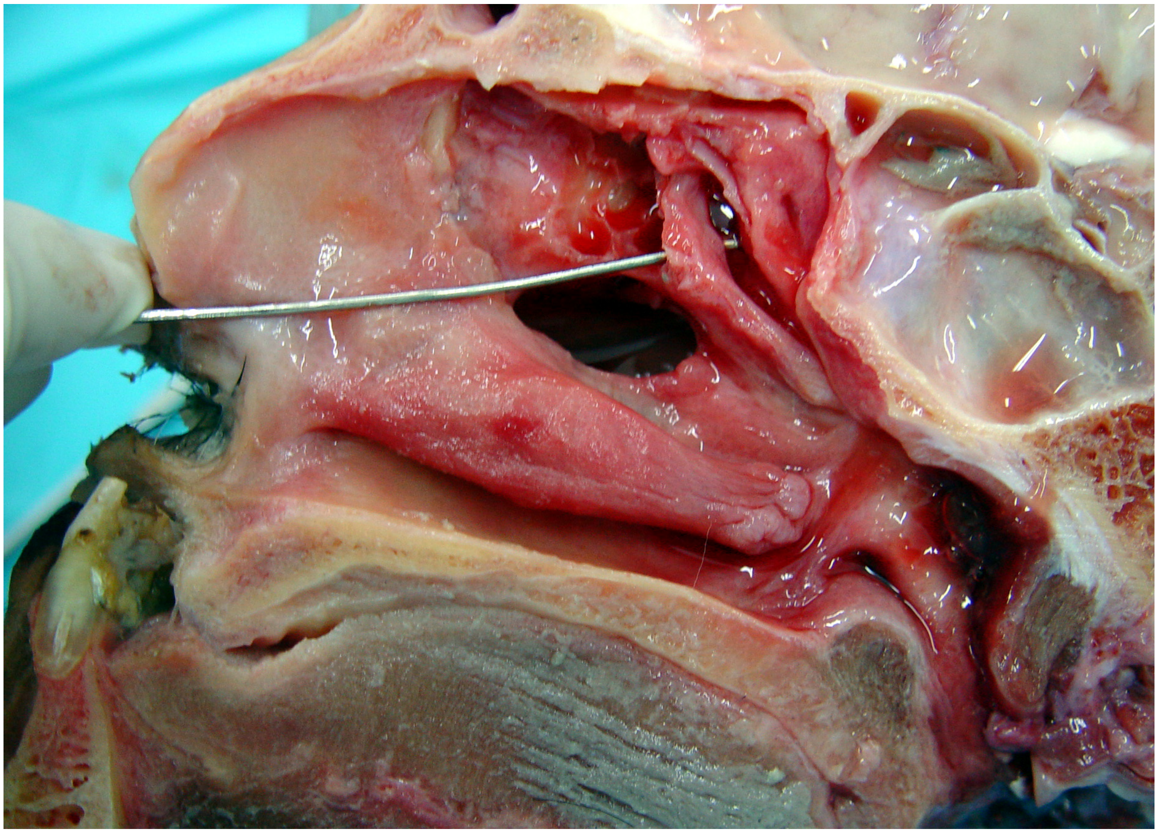


FIG 35

BASAL LAMELLA OF THE MIDDLE TURBINATE
SAGITTAL CADAVERIC DISSECTION SPECIMEN

A probe is placed through the basal lamella of the middle turbinate in this sagittal cadaveric specimen. This illustrates the path taken during endoscopic dissection, passing through the uncinate process, the anterior wall of the ethmoid bulla and the basal lamella of the middle turbinate and stopping short at the attachment of the superior turbinate. The distal end of the probe is seen at the superior meatus formed by the posterior ethmoid cells inferior in the superior meatus. The superior turbinate is an important anatomical landmark to approach the sphenoid sinus endoscopically

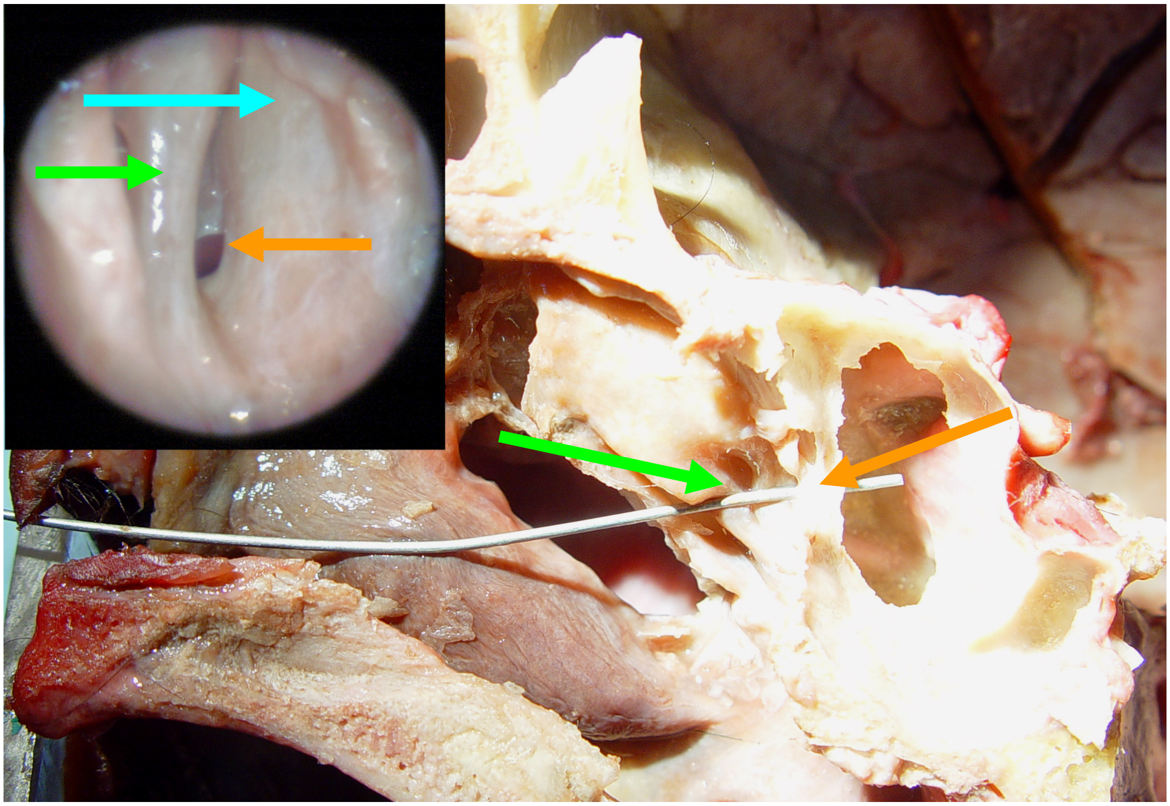


FIG 35A

SPHENOID SINUS : TRANSETHMOID/TRANSNASAL APPROACH.
SAGITTAL CADAVERIC DISSECTION SPECIMEN
ENDOSCOPIC VIEW OF CADAVERIC SPECIMEN : RIGHT NASAL CAVITY

A probe is placed through the sphenoid sinus ostium into the sphenoid sinus.
In the endoscopic view, the sphenoid sinus ostium (Orange Arrow Endoscopic View) is seen between the attachment of the posterior end of the superior turbinate laterally(Green Arrow Endoscopic View) and the nasal septum (Blue Arrow Endoscopic View) medially.
A safe endoscopic approach to the sphenoid sinus is to identify the sphenoid sinus ostium in relation to the superior turbinate attachment posteriorly and to enter into the sphenoid sinus via the sphenoid sinus ostium.
The sphenoethmoid recess is the space between the superior (and supreme, if present) turbinate laterally, the roof of the nose superiorly, and the nasal septum medially.

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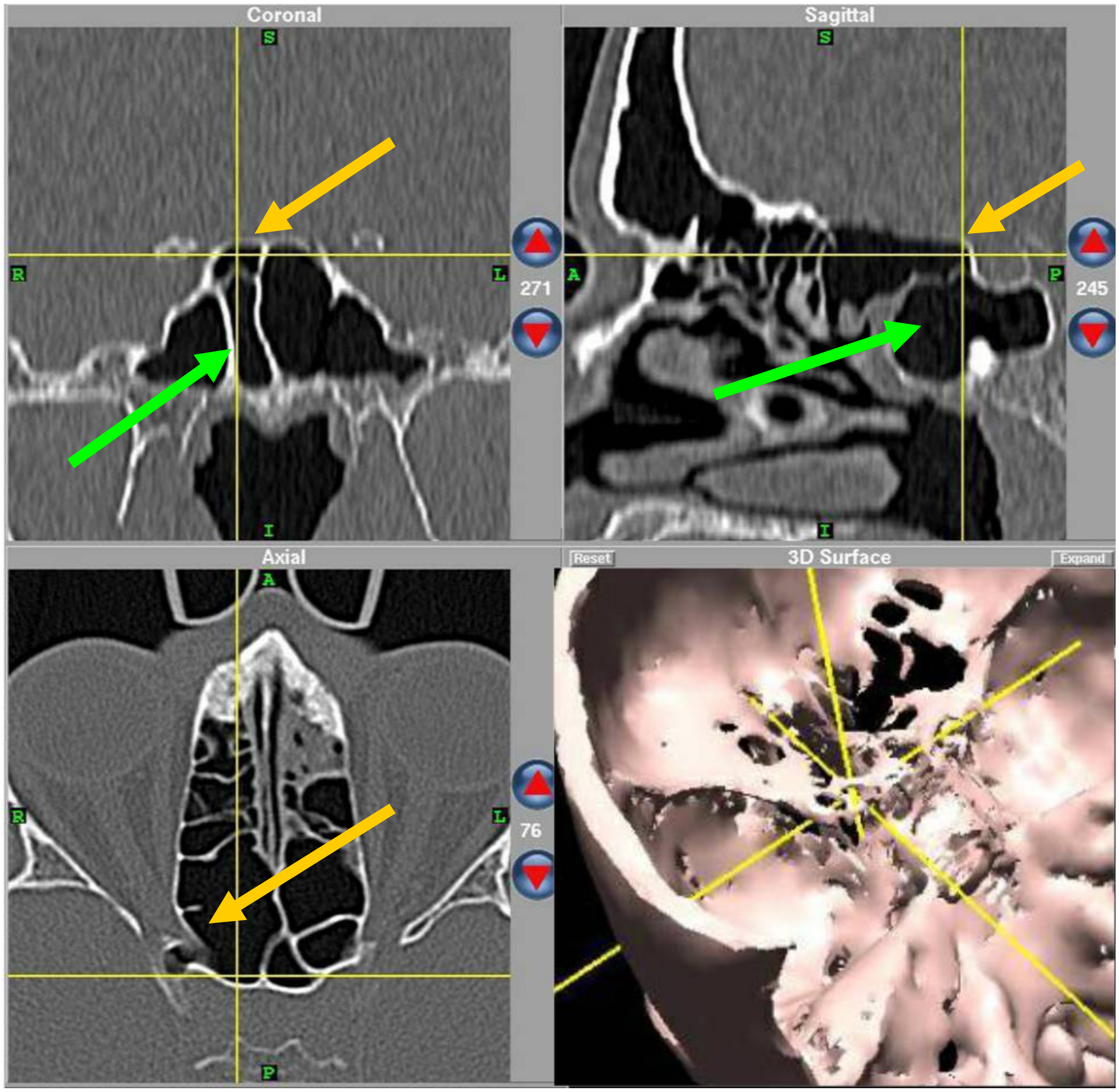

FIG 36

SPHENOETHMOID CELL / ONODI CELL
TRIPLANAR CT IMAGES PLANNING VIEW

Sphenoethmoid cells / Onodi cells (Orange Arrow Coronal, Sagittal) are the most posterior ethmoid cells pneumatizing lateral and superior to the sphenoid (Green Arrow Coronal and Sagittal) and intimately associated with the optic nerve.[2]
The optic nerve is adjacent to this cell, in this patient the optic nerve appears to be dehiscent within this Sphenoethmoid cell.(Orange Arrow Axial).
The Three Dimensional Reconstructed View from Posterior shows the position of the sphenoethmoid cell in relation to the sella and the anterior clinoid process.

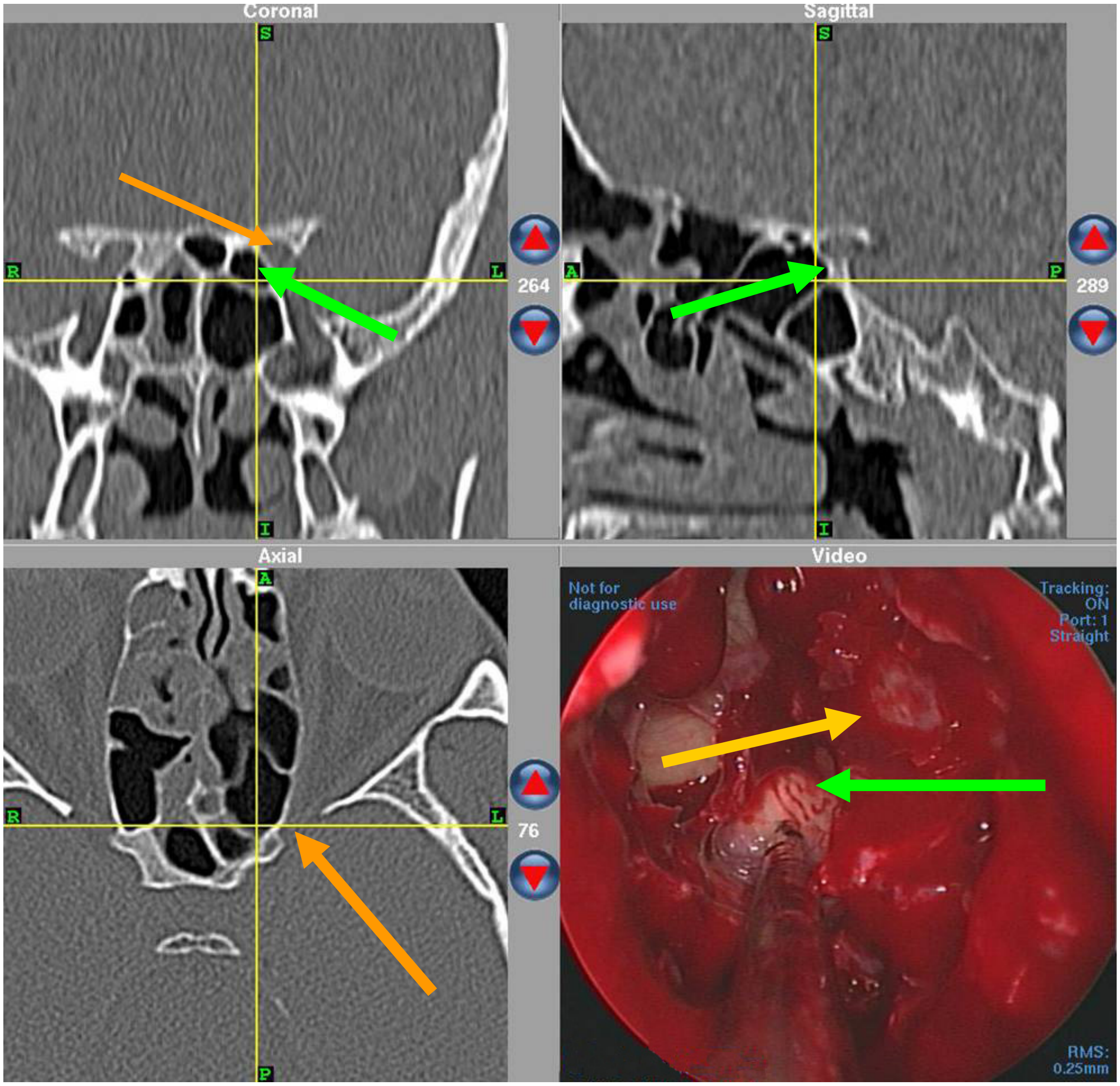

FIG 37

SPHENOETHMOID CELL / ONODI CELL
TRIPLANAR CT IMAGES OPERATIVE VIEW

During Surgical Navigation, the tracker is placed in the Sphenoethmoid cell (Green Arrow Operative View). Note the Onodi cell above the sphenoid (Green Arrow Coronal), extending posteriorly over the sphenoid sinus (Green Arrow Sagittal) and the close proximity of the optic nerve (Orange Arrow Coronal) to the Sphenoethmoid cell (Orange Arrow Axial).
In this patient, the optic canal bulge is absent in the sphenoethmoid cell although the axial and coronal CT views clearly show the optic nerve to be adjacent to the sphenoethmoid cell. Yeoh et al has pointed out that it is in sphenoethmoid cells such as these that the likelihood of injury to the optic nerve is high. The likely path of the optic nerve is indicated by the Orange Arrow Operative View.

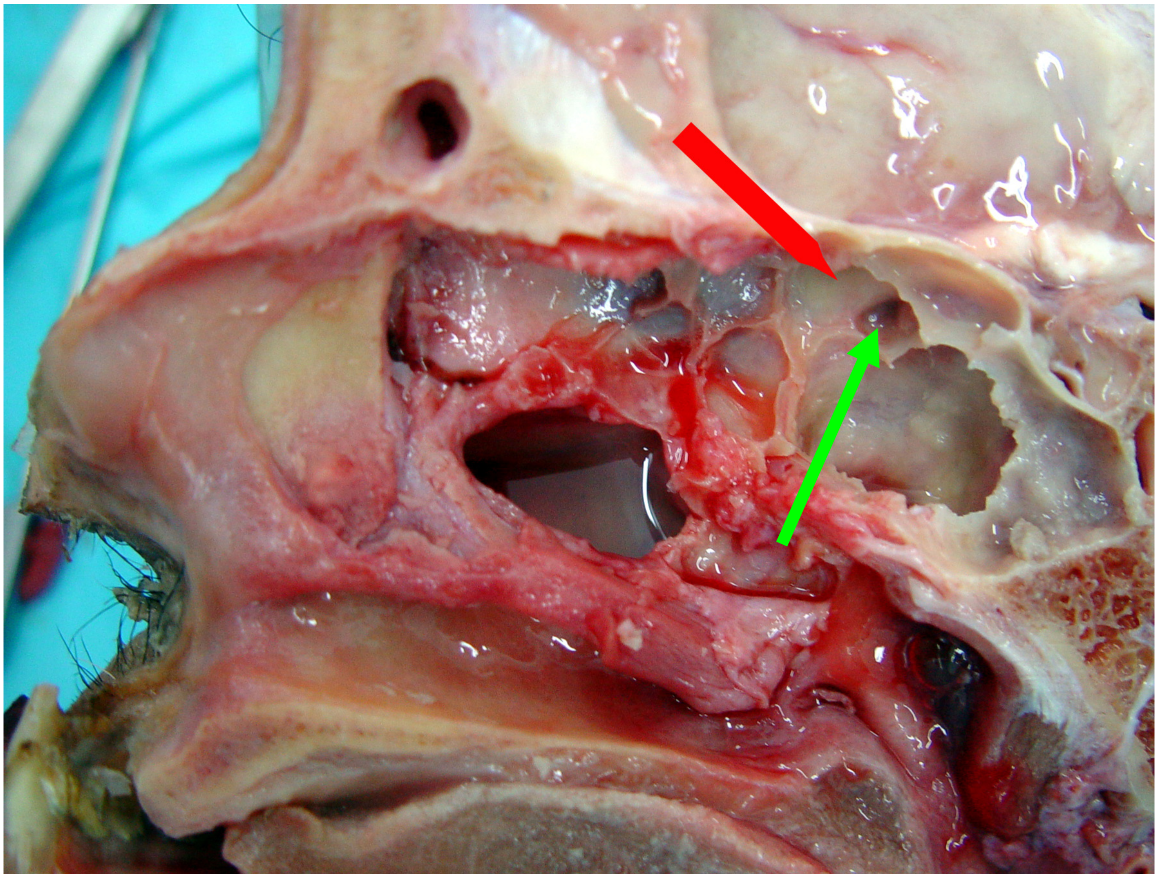

FIG 38

SPHENOETHMOID CELL / ONODI CELL
SAGITTAL CADAVERIC DISSECTION SPECIMEN

This Sagittal Cadaveric Specimen demonstrates a Sphenoethmoid cell with the Optic nerve (Red Arrow) seen within this cell. The infra-optic recess separates the optic nerve from the internal carotid artery.(Green Arrow). It is important to note that the internal carotid artery ascends close to the optic nerve superiorly either in the sphenoid sinus or as in this case in the Sphenoethmoid cell. In the procedure of Optic Nerve Decompression, one must be mindful of this to avoid the catastrophic complication of an endoscopically created internal carotid artery bleed in the nose.

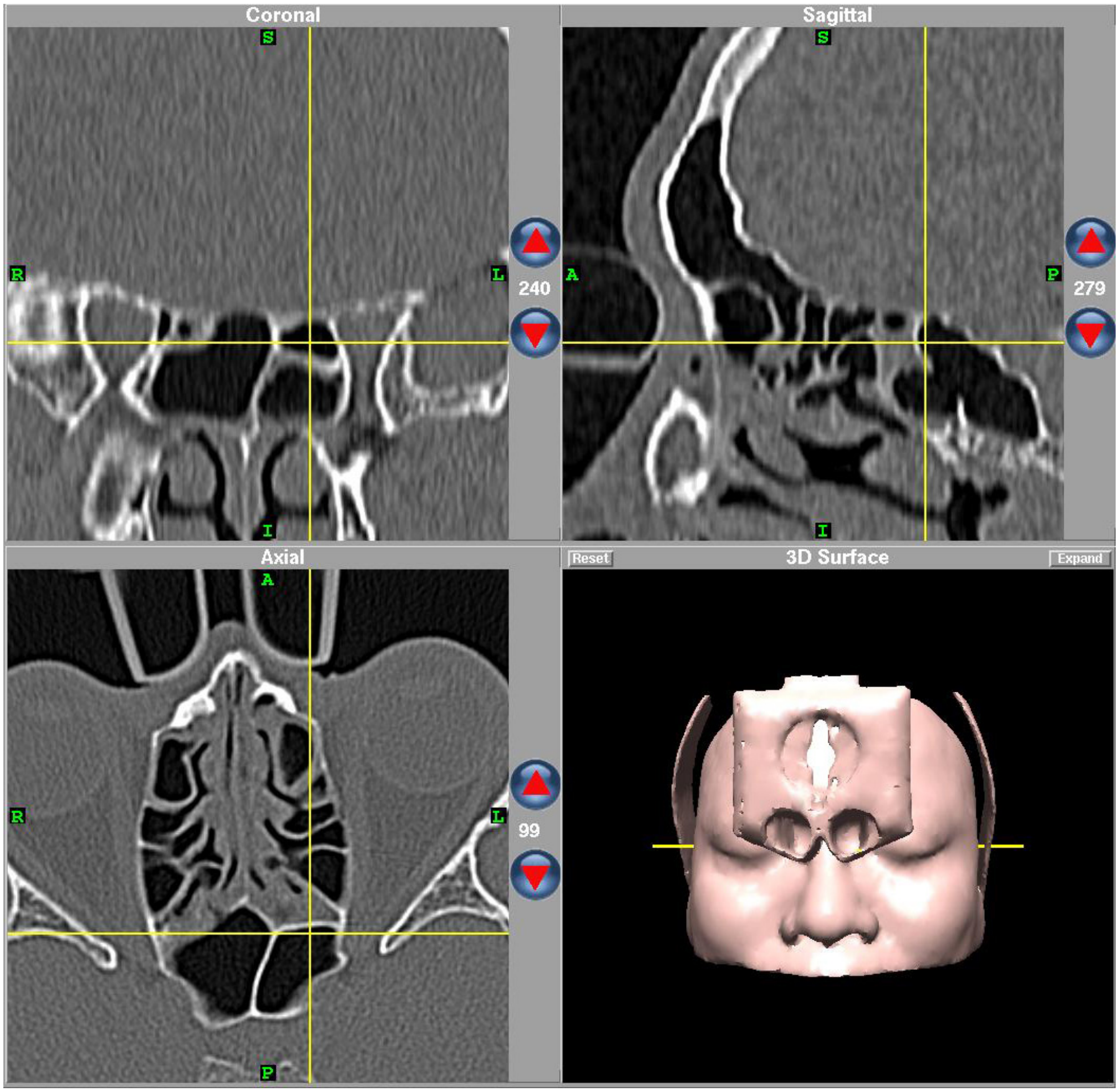

FIG 39

DIFFERENTIATING BETWEEN THE SPHENOID SINUS AND THE SPHENOETHMOID CELL.
TRIPLANAR CT IMAGES PLANNING VIEW

The Coronal View is highly suggestive of a Sphenoethmoid Cell with a definite horizontal bar of bone seemingly separating the sphenoid sinus below from the sphenoethmoid cell above.

The Sagittal and Axial views clearly show that the superior aspect of the sphenoid sinus is not associated with posterior pneumatization of a posterior ethmoid cell. The anterior wall of the sphenoid sinus is seen to protrude anteriorly toward the posterior ethmoid accounting for the line across the sphenoid sinus on the Coronal view.

FIG 40

SPHENOID SINUS : CONCHAL TYPE [3]
CT IMAGES : AXIAL AND CORONAL VIEWS.

The conchal type is characterized by the presence of solid bone below the sella without any pneumatization. [3]
There were no conchal type of sphenoid sinus encountered in this report which examined CT scans of adult patients. The CT views above are those of a 6 year old child. The sphenoid sinus begins development during the 3rd fetal month as the sphenoethmoidal recess constricts and draws the superior concha upward. Secondary pneumatization does not begin until 10 years of age.

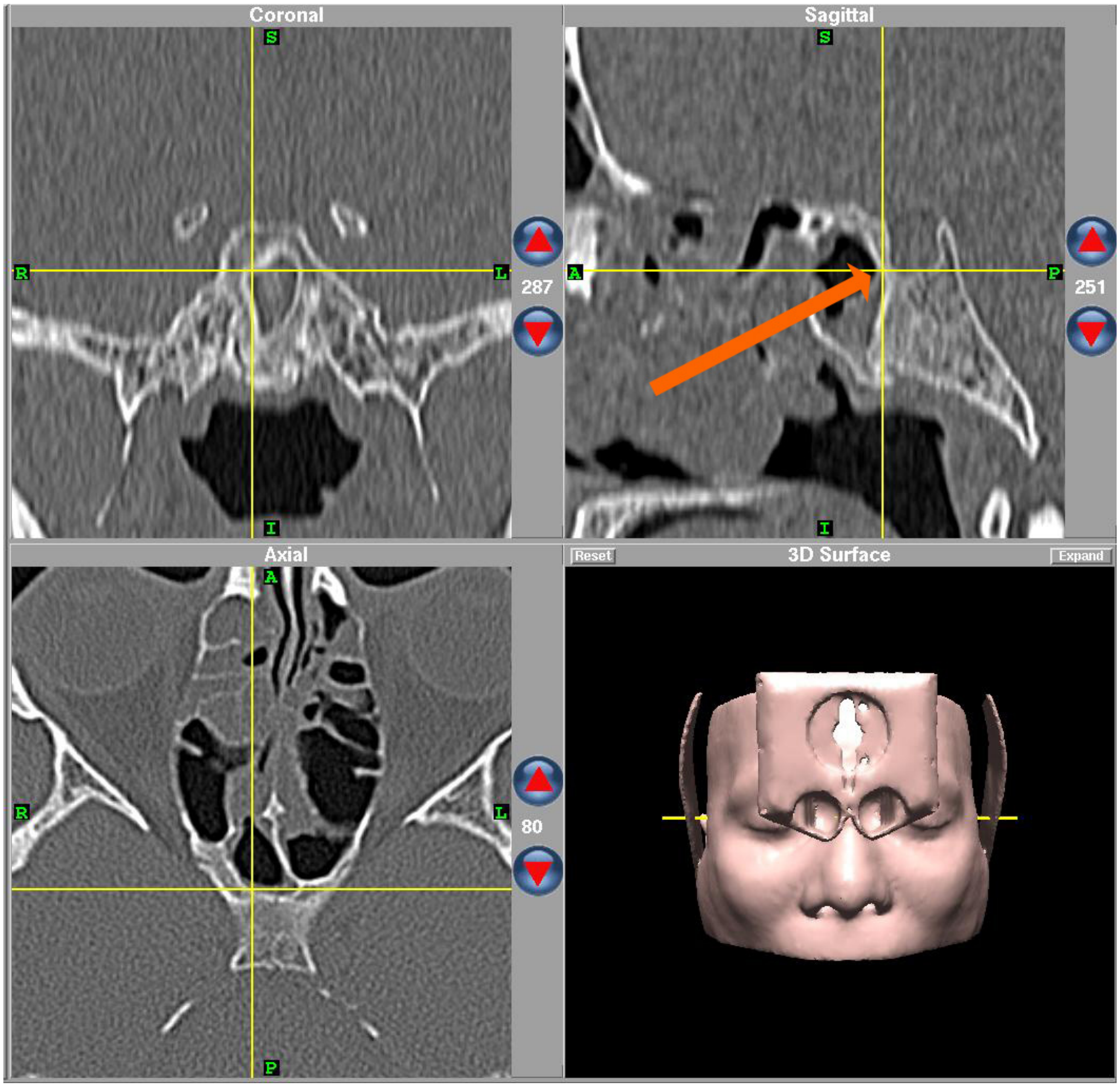

FIG 41

SPHENOID SINUS - PRESELLAR TYPE [3]
TRIPLANAR CT IMAGES PLANNING VIEW

Pneumatization is limited to the region anterior to the plane that is parallel to the anterior sellar wall. (Orange Arrow Sagittal)

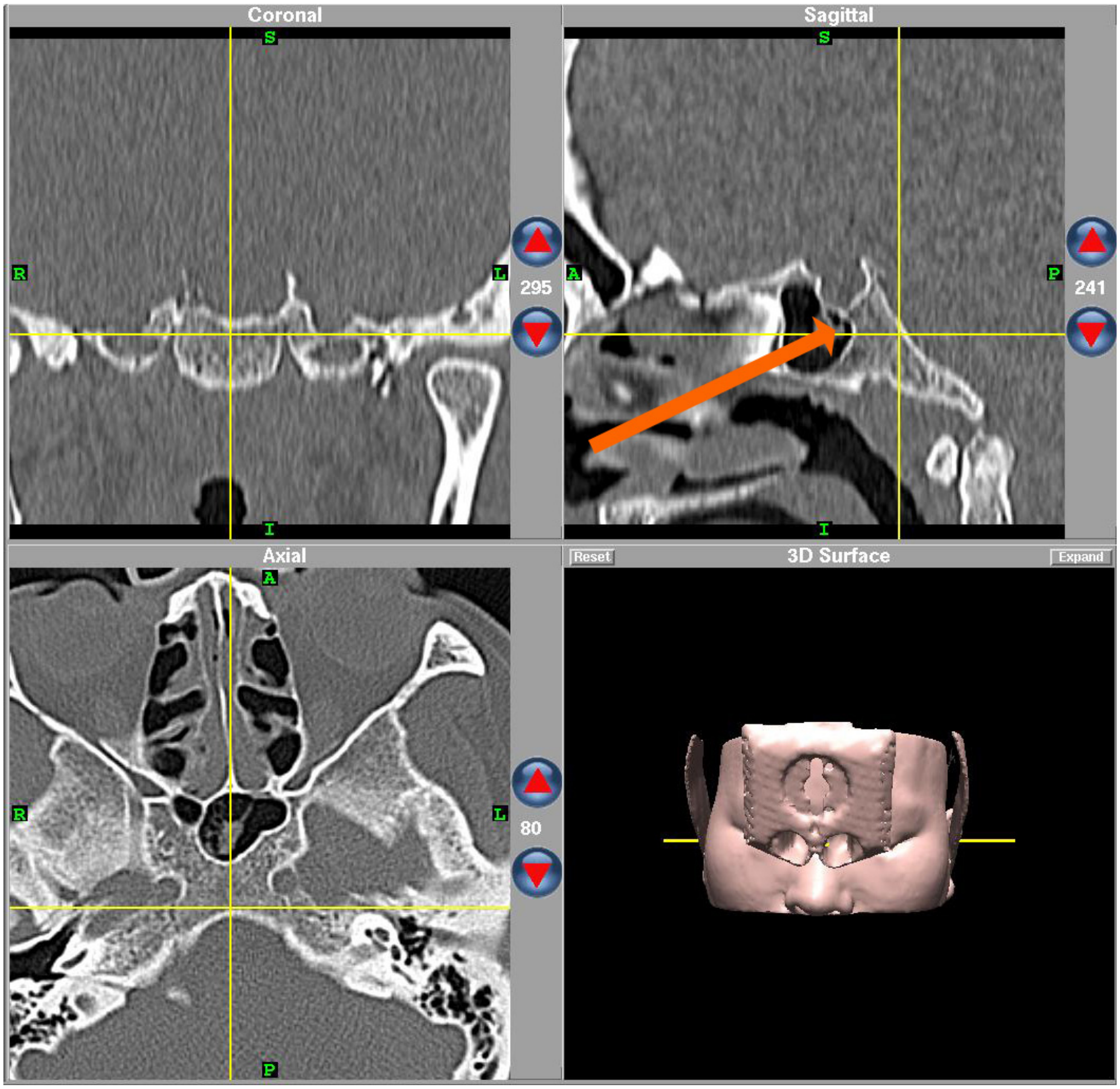

FIG 42

SPHENOID SINUS - SELLAR TYPE [3]
TRIPLANAR CT IMAGES PLANNING VIEW

Pneumatization extends beyond the anterior wall but does not penetrate past the posterior sellar wall. (Orange Arrow Sagittal).

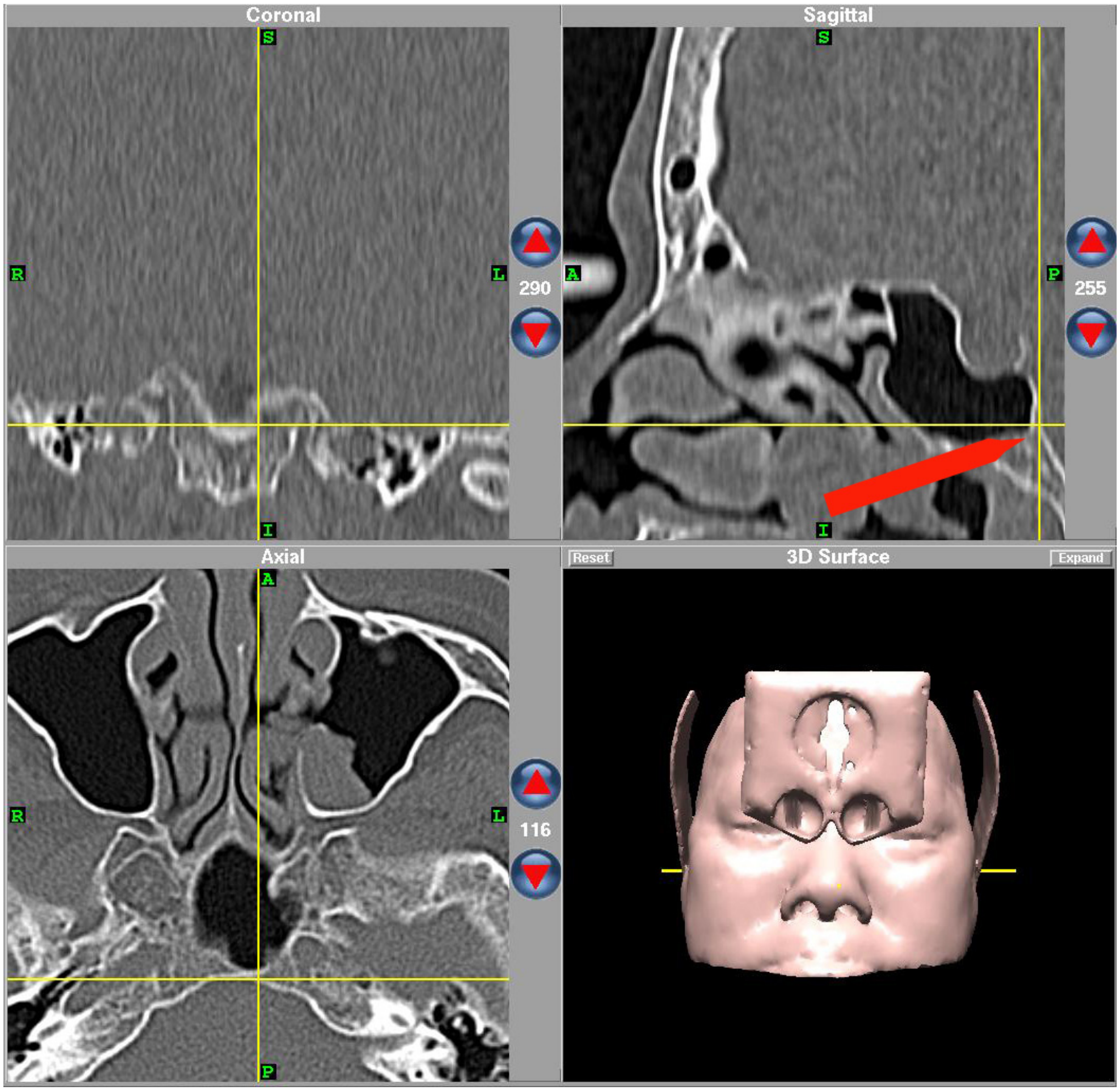

FIG 43

SPHENOID SINUS - POSTSELLAR TYPE [3]
TRIPLANAR CT IMAGES PLANNING VIEW

Pneumatization extends beyond the posterior wall of the sella. (Red Arrow Sagittal).

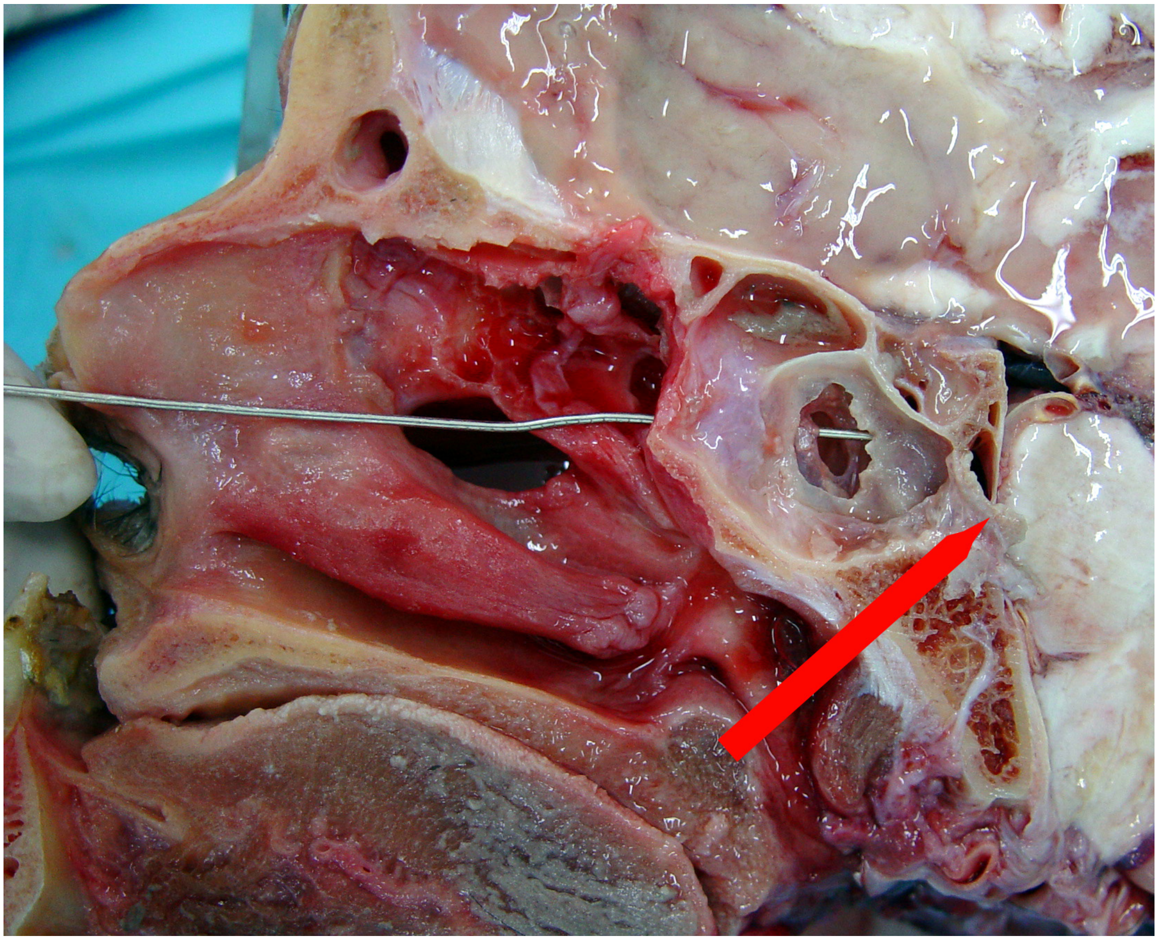
FIG 44

SPHENOID SINUS – POST SELLAR
SAGITTAL CADAVERIC DISSECTION SPECIMEN

In this Sagittal Cadaveric Dissection Specimen , a probe is placed through the anterior wall of the right sphenoid sinus and through a dissected central sphenoid sinus wall allowing the distal end of the probe to be seen at the left sphenoid sinus.
The sellar type of pneumatization of the sphenoid is seen in this specimen. (Red Arrow)

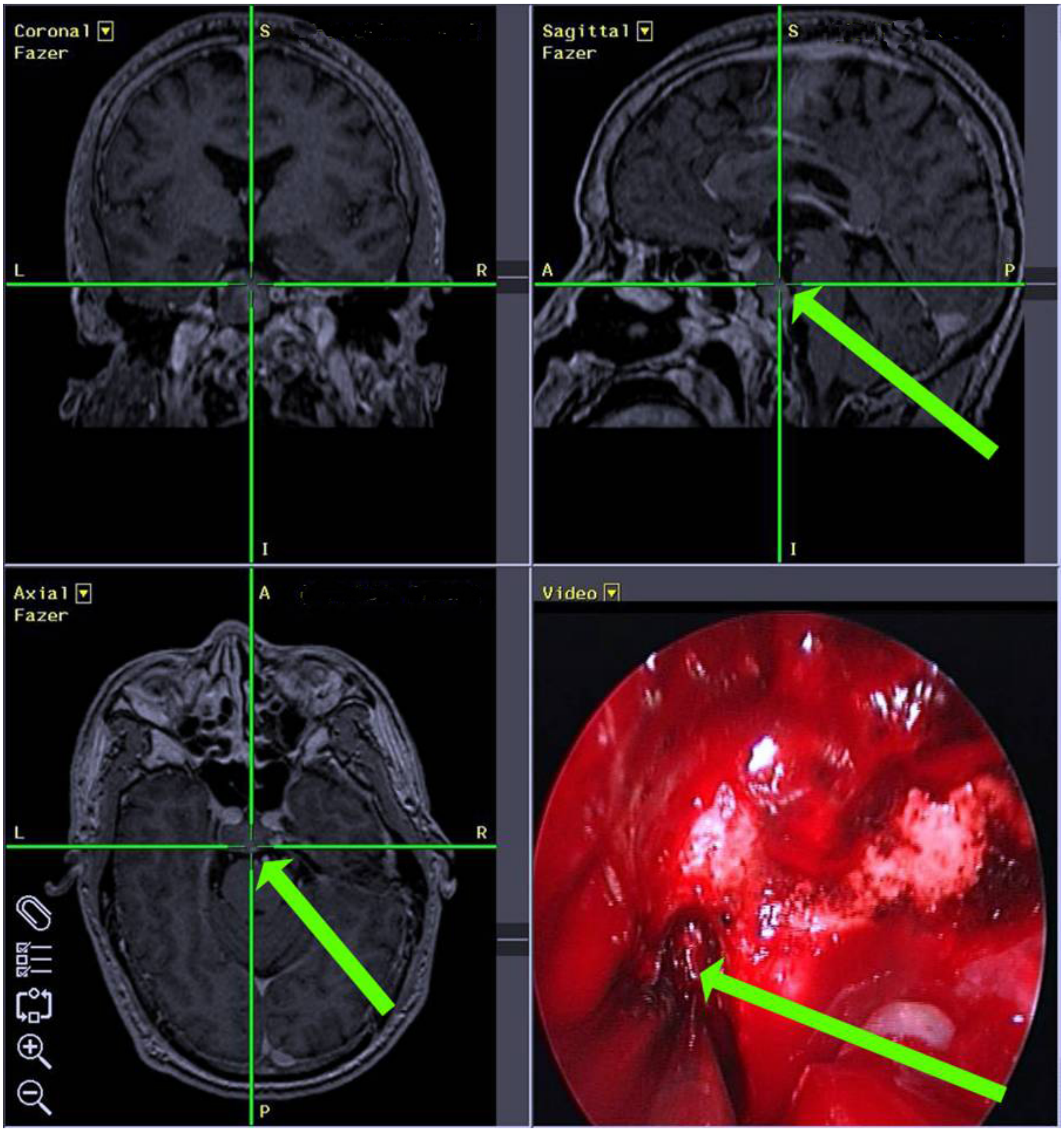

FIG 45

SPHENOID SINUS – POST SELLAR
TRIPLANAR CT IMAGES OPERATIVE VIEW

A pneumatized Sphenoid Sinus (Post Sellar) allows for endoscopic surgical access to skull base lesions , in this case, a clival tumor. The tracker is placed beyond the clival tumor just anterior to the brain stem.(Green Arrow All Views). Instrumentation beyond this region may lead to the catastrophic consequence of hemorrhage from the basilar artery.

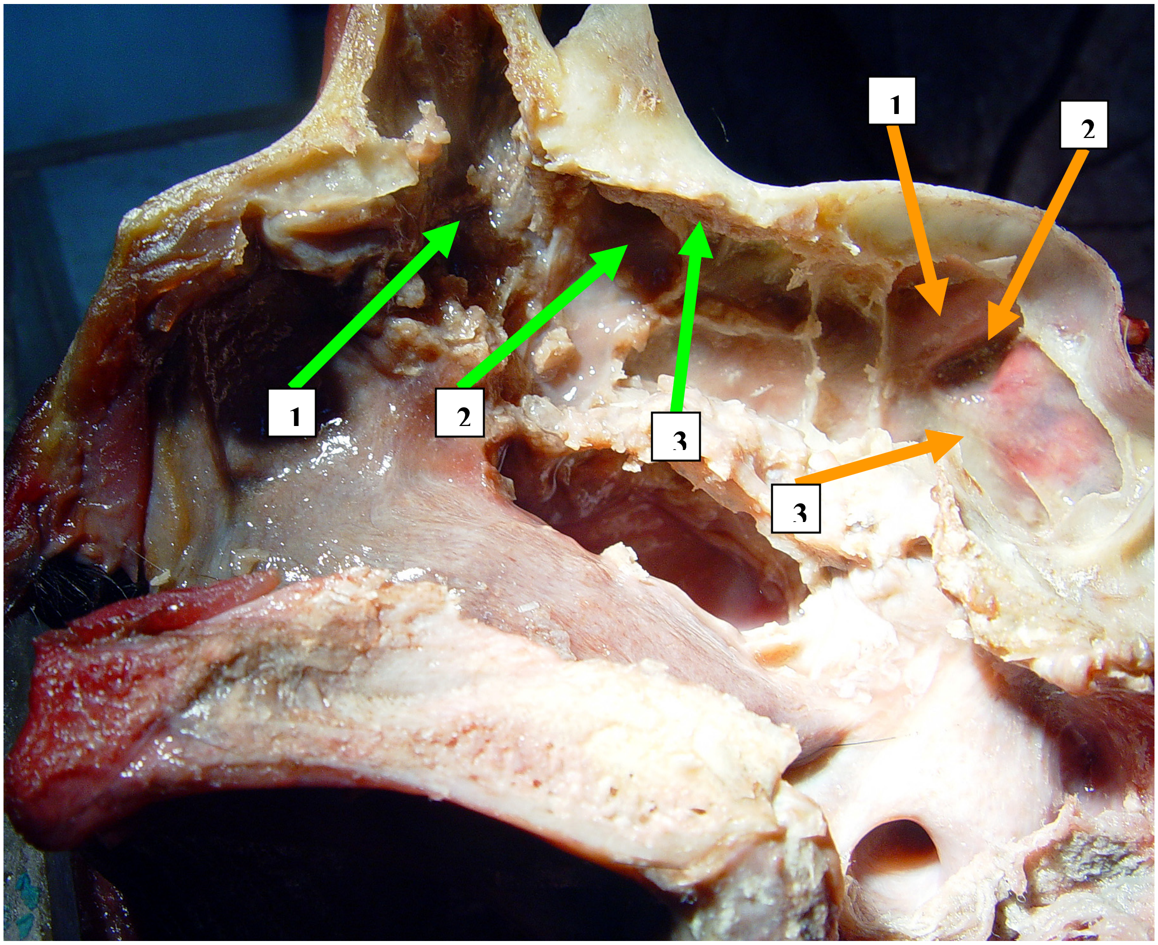

FIG 46.

SPHENOID SINUS – RELATIONSHIP OF THE OPTIC NERVE AND INTERNAL CAROTID ARTERY
SAGITTAL CADAVERIC DISSECTION SPECIMEN

The optic nerve tubercle (Orange Arrow 1) and the infra-optic recess (Orange Arrow 2) is shown. Note the tortuous course of the internal carotid artery (Orange Arrow 3) at the lateral wall of the sphenoid, first extending anteriorly from its inferior entry followed by an acute turn and then extending posteriorly below the infra-optic recess.

FRONTAL RECESS AND SUPRA-ORBITAL ETHMOID CELL

The frontal recess has been dissected (Green Arrow 1) and the presence of a supra-orbital ethmoid cell (Green Arrow 2) noted. The anterior ethmoid artery (Green Arrow 3) is shown in the skull base posterior to the opening of the supra-orbital ethmoid cell.

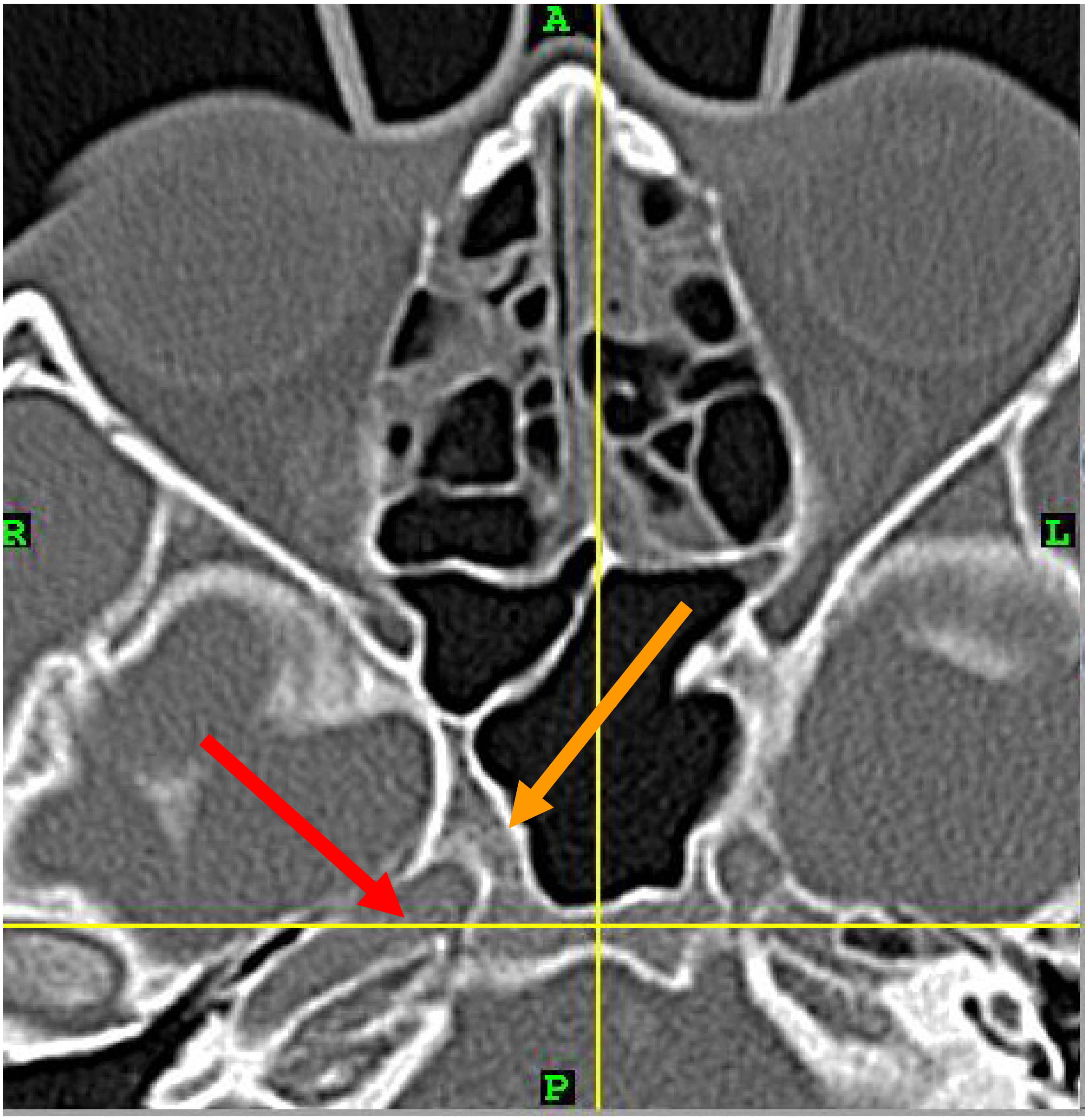

FIG 47

SPHENOID SINUS AND INTERNAL CAROTID ARTERY
TYPE 0 – NO EXPOSURE [3]
TRIPLANAR CT IMAGES PLANNING VIEW,AXIAL PLANE ONLY.

Extent of sphenoid pneumatization around the retrosellar segment of the Internal Carotid Artery. (ICA)

Orange Arrow Axial indicates a thick segment of clival bone separating the ICA from the sphenoid sinus.
Red Arrow indicates Internal Carotid Artery

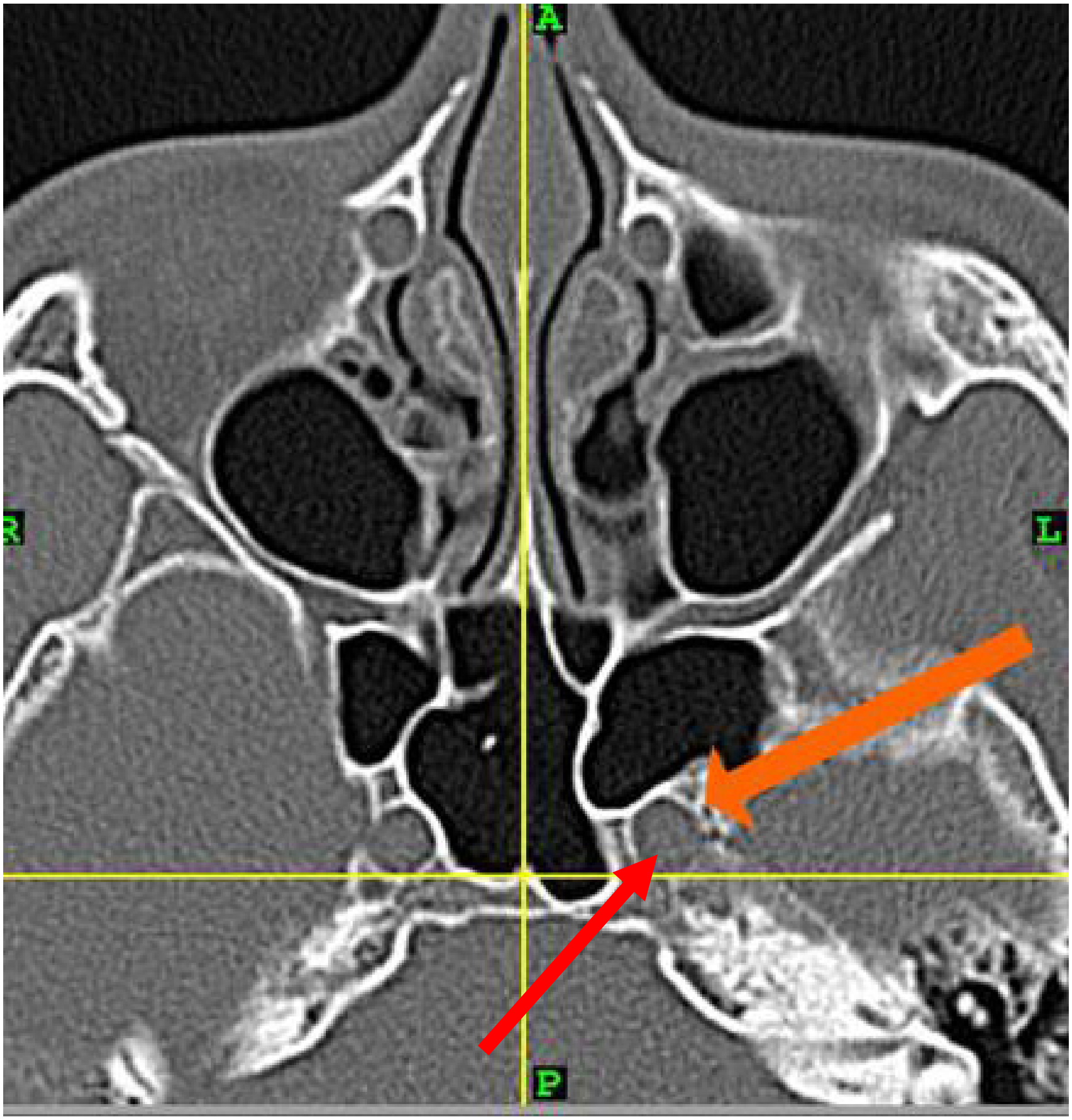

FIG 48

SPHENOID SINUS AND INTERNAL CAROTID ARTERY
TYPE 1 – EXPOSURE OF < 90 DEGREES [3]
TRIPLANAR CT IMAGES PLANNING VIEW , AXIAL PLANE ONLY.

Extent of sphenoid pneumatization around the retrosellar segment of the Internal Carotid Artery (ICA).

Orange Arrow Axial indicates a thin segment of bone separating the ICA from the sphenoid sinus.
Red Arrow indicates Internal Carotid Artery

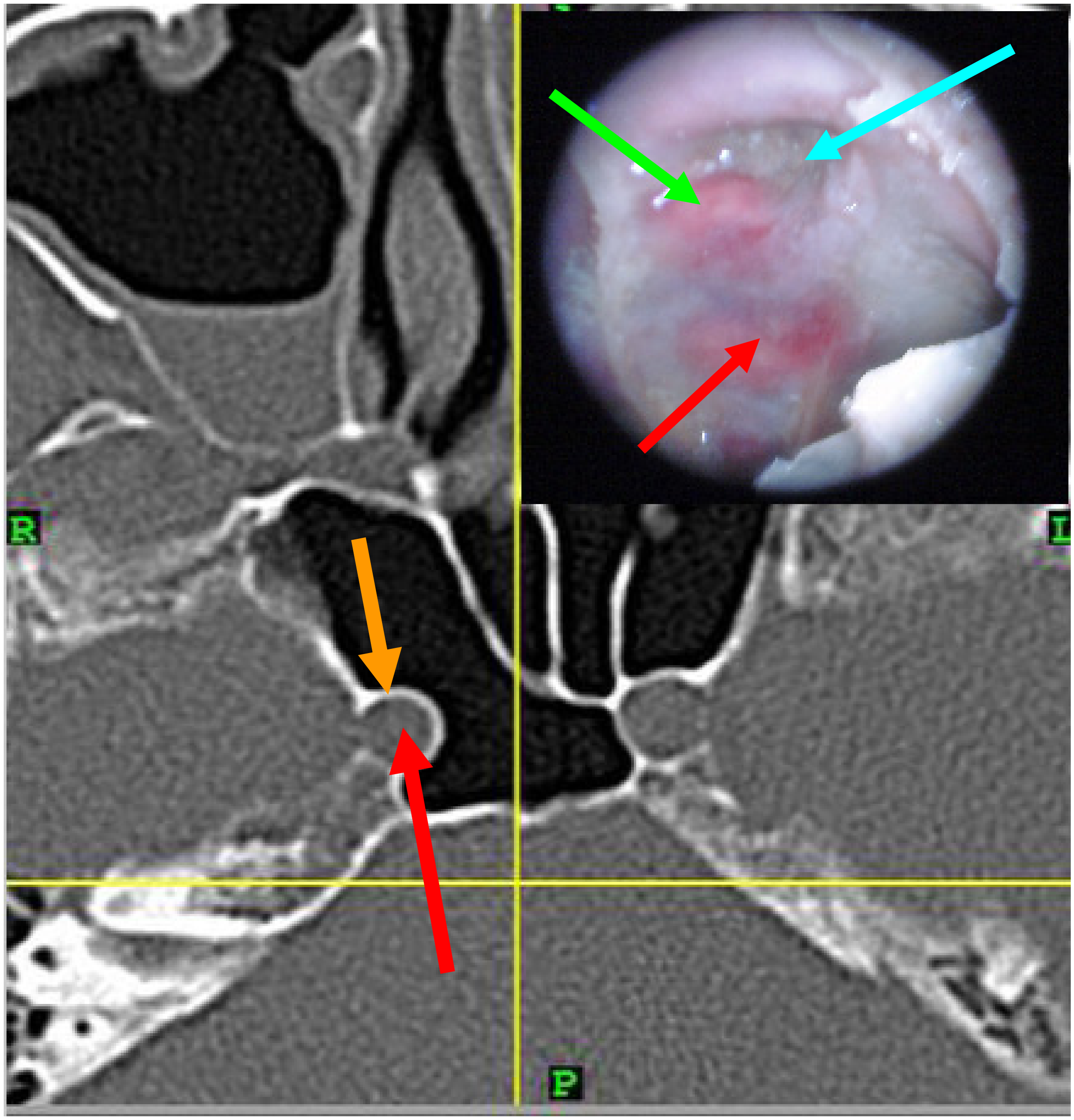

FIG 49

SPHENOID SINUS AND INTERNAL CAROTID ARTERY
TYPE 3 – EXPOSURE OF > 180 DEGREES [3]
TRIPLANAR CT IMAGES PLANNING VIEW, AXIAL PLANE ONLY
ENDOSCOPIC VIEW OF CADAVERIC SPECIMEN

Extent of sphenoid pneumatization around the retrosellar segment of the Internal Carotid Artery (ICA).
Red Arrow Indicates Internal Carotid Artery
The Internal Carotid Artery protrudes prominently into the sphenoid sinus lumen. (Orange Arrow Axial)

Note on the endoscopic view the of the internal carotid artery, and its tortuous course, extending first anteriorly from inferior (Orange Arrow Endoscopic View) to posteriorly at its superior course. (Green Arrow Endoscopic View). The infraoptic recess is also seen. (Blue Arrow Endoscopic View)

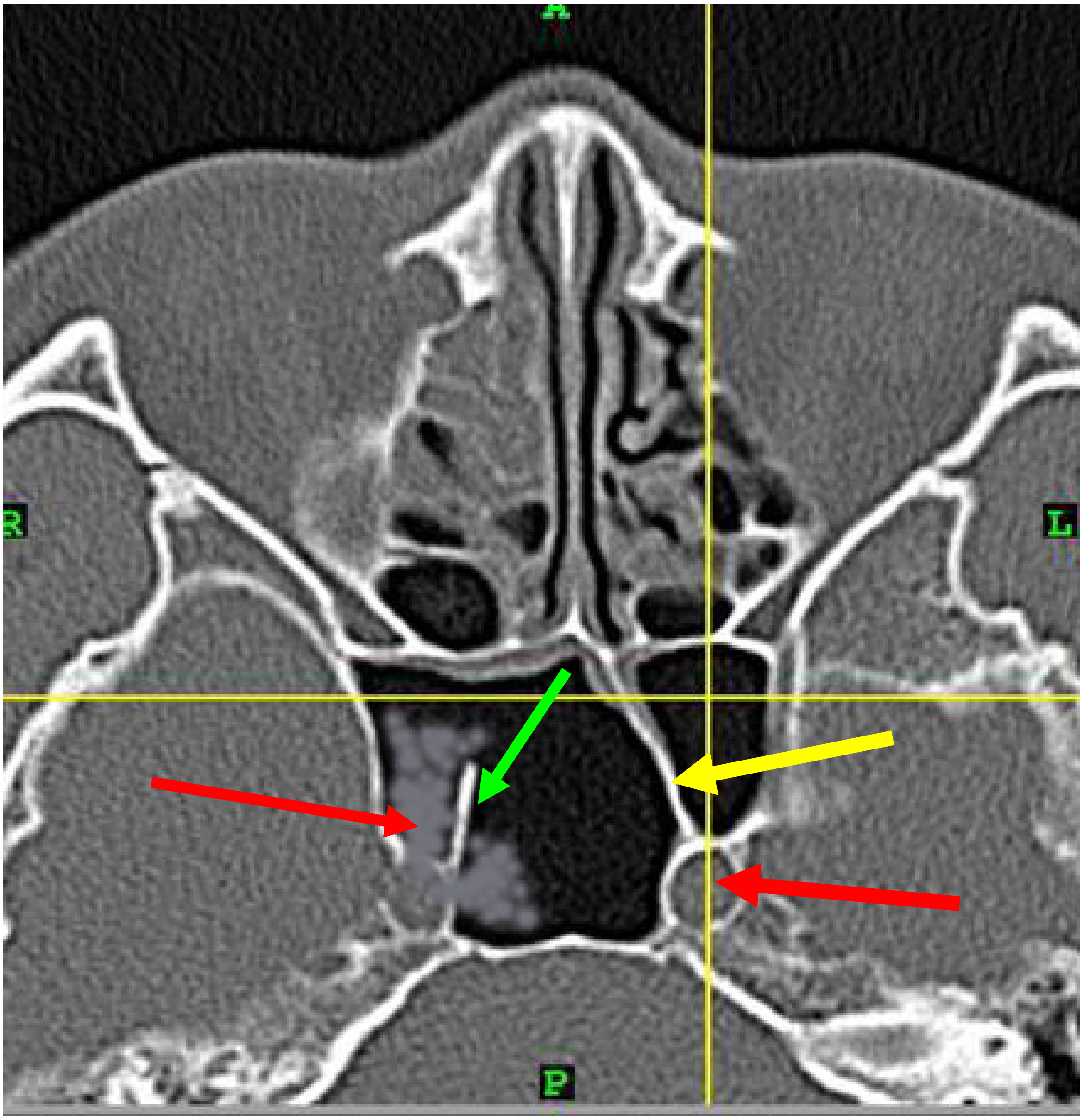

FIG 50

SPHENOID SINUS : SEPTAL INSERTION ONTO THE PATH OF THE INTERNAL CAROTID ARTERY.
TRIPLANAR CT IMAGES PLANNING VIEW,AXIAL PLANE ONLY

This septal insertion may be a complete septum arising from the anterior wall of the sphenoid sinus and inserting upon the posterior wall (Yellow Arrow Axial) or an incomplete septum inserting on the posterior wall only. (Green Arrow)

This is an important anatomical concept. In surgery requiring removal of the sphenoid septum, the surgeon should cut the septum and not attempt to avulse it as this may lead to the catastrophic complication of internal carotid artery hemorrhage in the nose. (Red Arrow Axial).
Red Arrow indicates Internal Carotid Artery

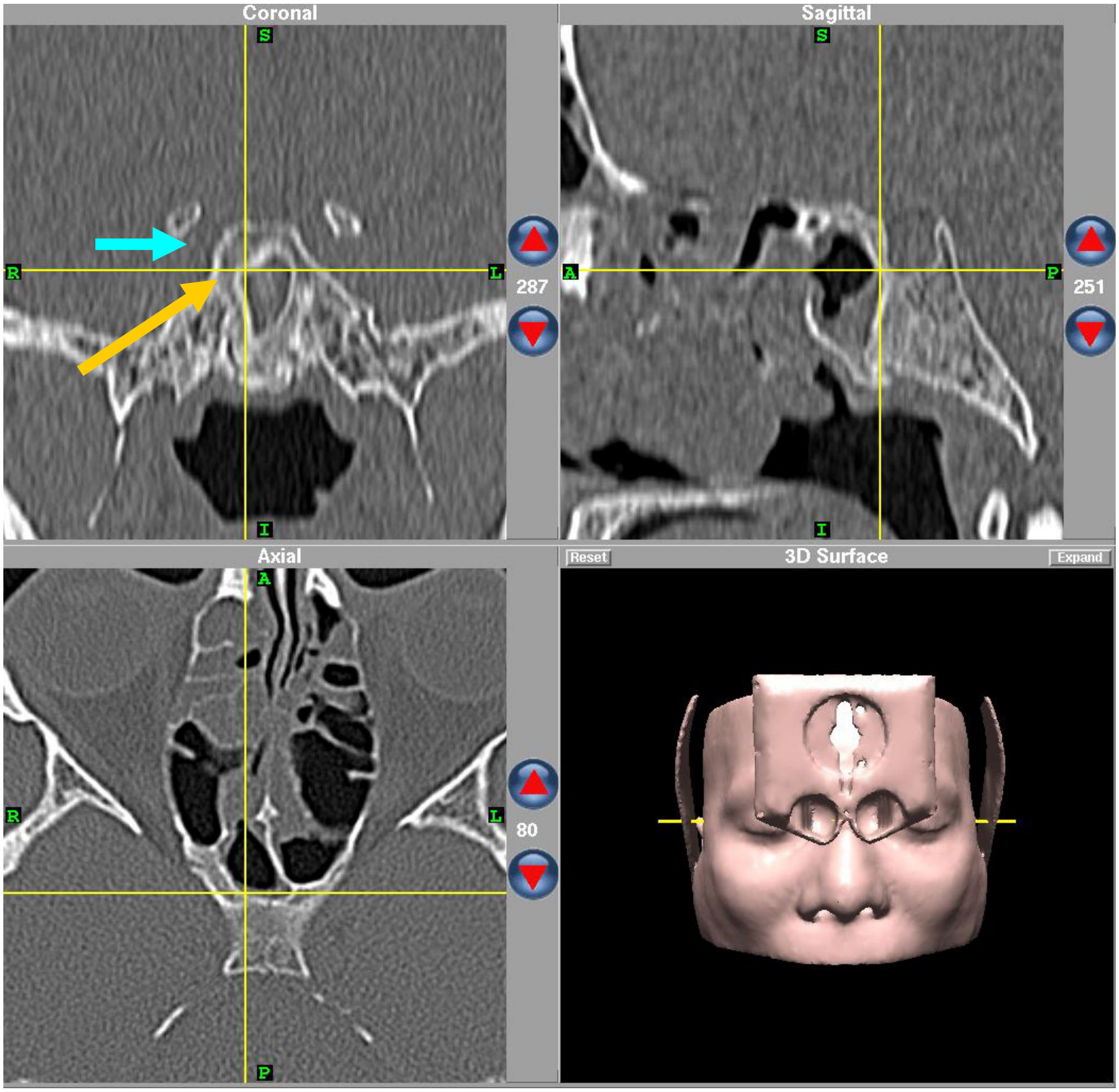

FIG 51

SPHENOID SINUS AND THE OPTIC NERVE
TRIPLANAR CT IMAGES PLANNING VIEW

DEGREE OF PNEUMATIZATION IN THE VICINITY OF OPTIC NERVE.
TYPE 0 - NO ADJACENT PNEUMATIZATION [4]
(Orange Arrow Coronal)
Blue Arrow indicates Optic Nerve

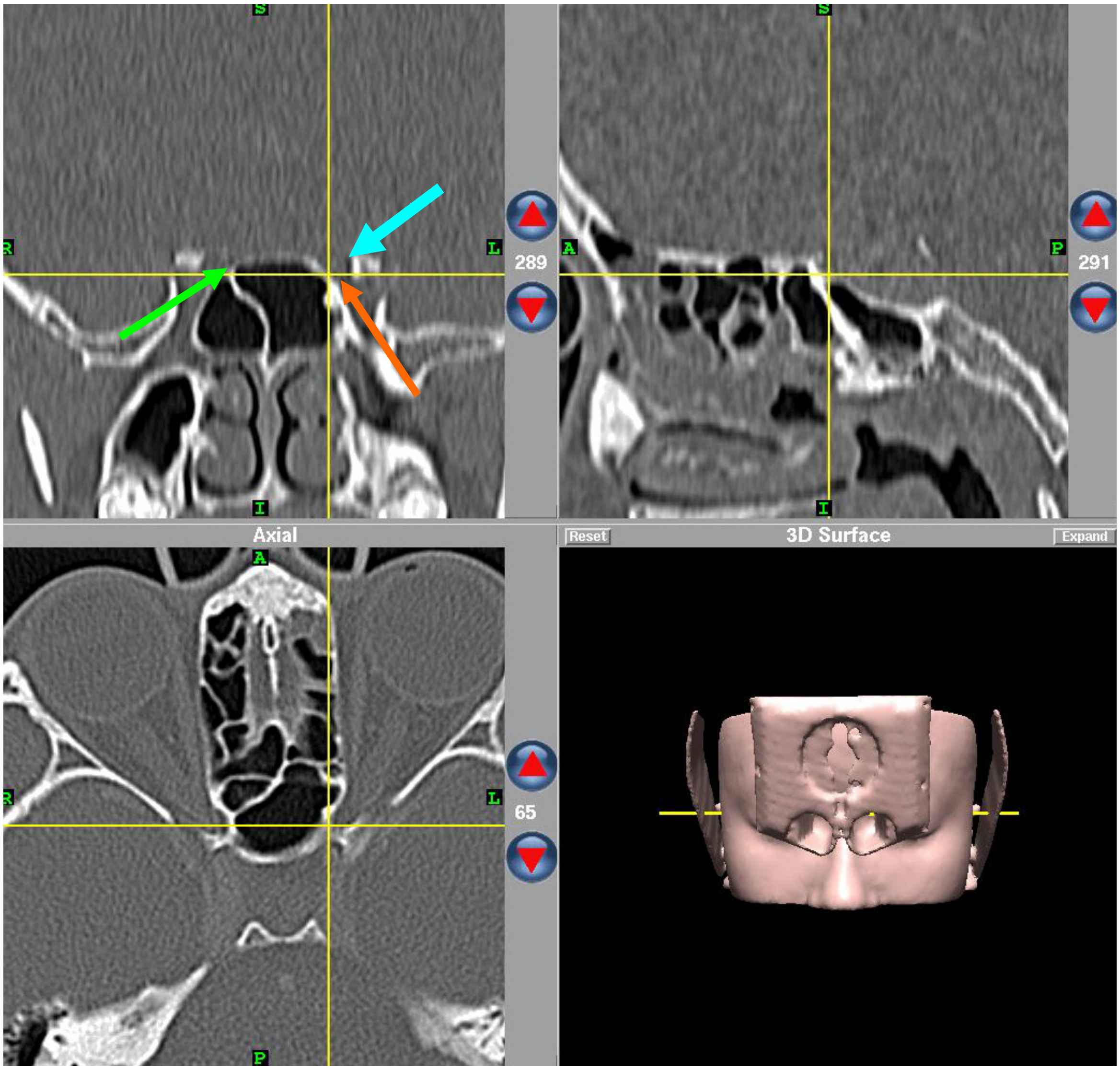

FIG 51A

SPHENOID SINUS AND THE OPTIC NERVE
TRIPLANAR CT IMAGES PLANNING VIEW

DEGREE OF PNEUMATIZATION IN THE VICINITY OF OPTIC NERVE.
TYPE 1 - PNEUMATIZATION ADJACENT TO OPTIC NERVE WITH NO SPHENOID INDENTATION.[1] (Orange Arrow Coronal)

Septal insertion on to the optic nerve on the right side is noted. (Green Arrow Coronal)

Blue Arrow indicates Optic Nerve

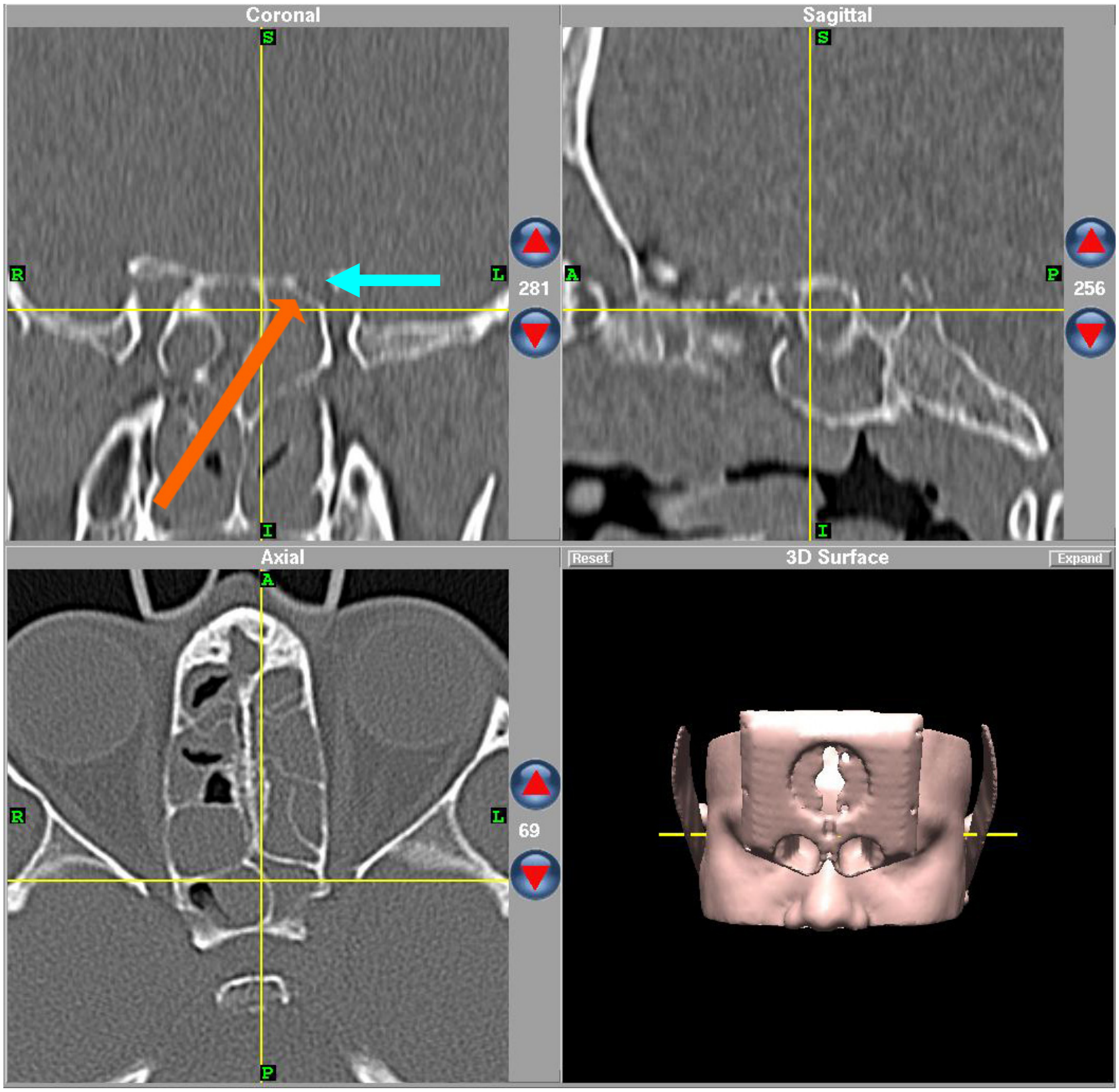

FIG 52

SPHENOID SINUS AND THE OPTIC NERVE
TRIPLANAR CT IMAGES PLANNING VIEW

DEGREE OF PNEUMATIZATION IN THE VICINITY OF OPTIC NERVE.
TYPE 2 - PNEUMATIZATION ADJACENT TO THE OPTIC NERVE WITH SPHENOID INDENTATION [4]

(Orange Arrow Coronal)
Blue Arrow indicates Optic Nerve

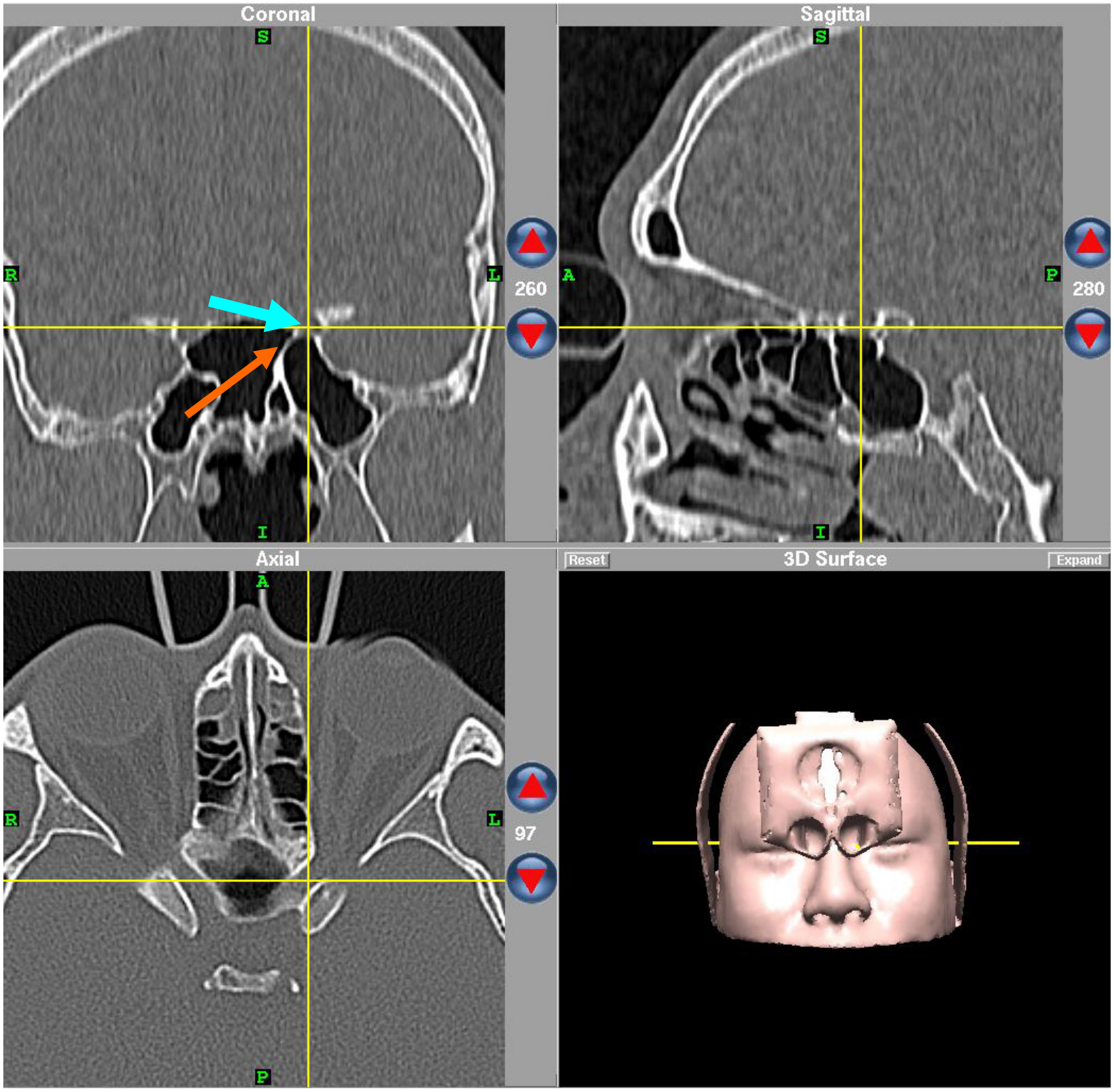

FIG 53

SPHENOID SINUS AND THE OPTIC NERVE
TRIPLANAR CT IMAGES PLANNING VIEW
DEGREE OF PNEUMATIZATION IN THE VICINITY OF OPTIC NERVE.
TYPE 3 - PNEUMATIZATION OF LESS THAN 50 % OF CIRCUMFERENCE OF THE OPTIC NERVE [4]
(Orange Arrow Coronal)

Septal insertion on to the optic nerve on the left side is noted.
Blue Arrow indicates Optic Nerve

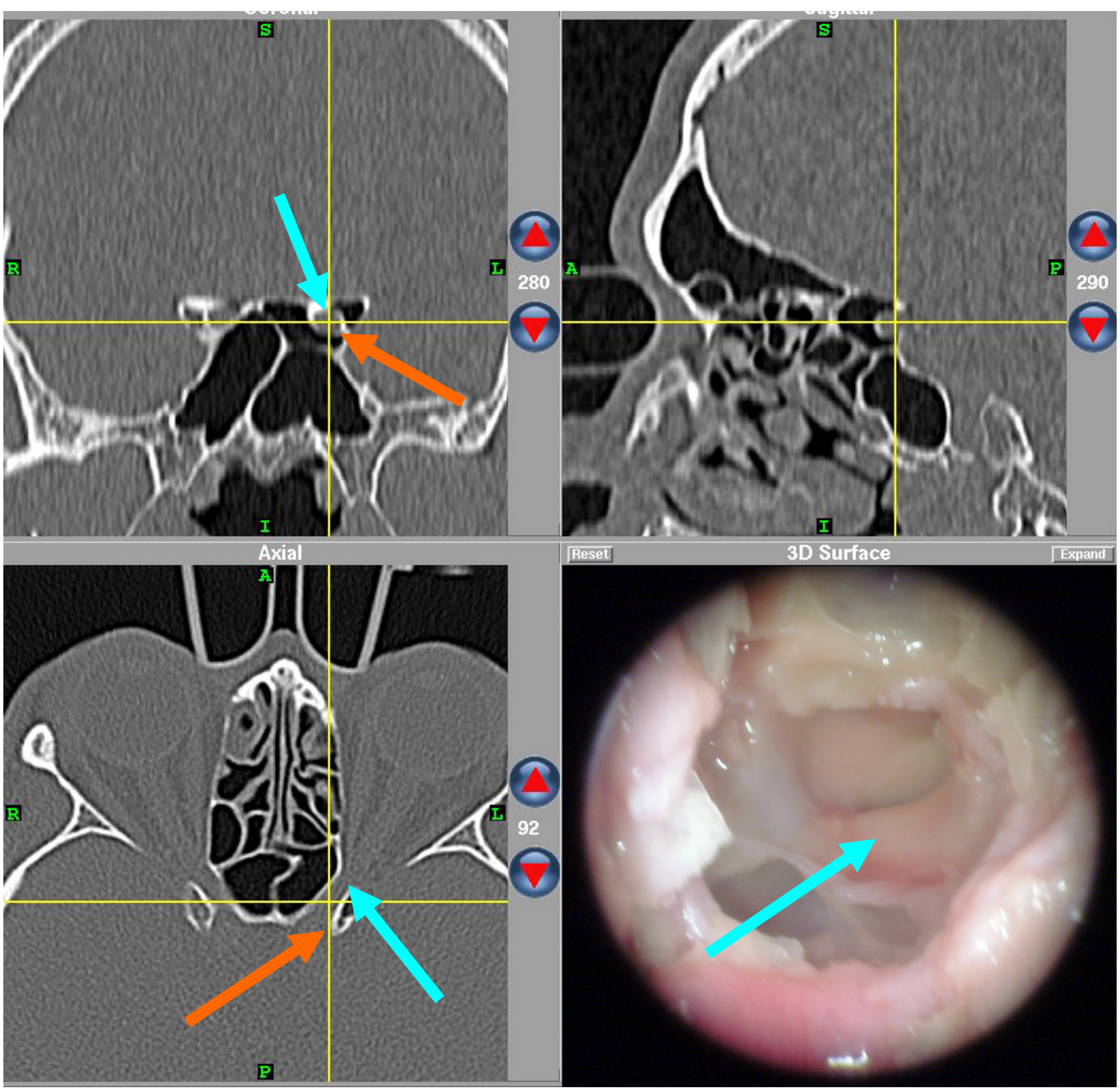

FIG 54

SPHENOID SINUS AND THE OPTIC NERVE
TRIPLANAR CT IMAGES PLANNING VIEW
ENDOSCOPIC VIEW OF CADAVERIC SPECIMEN
DEGREE OF PNEUMATIZATION IN THE VICINITY OF OPTIC NERVE.
TYPE 4 - PNEUMATIZATION OF MORE THAN 50% OF CIRCUMFERENCE OF THE OPTIC NERVE [4]
(Orange Arrow Coronal , Axial)

Note the air space posterior to the optic nerve on the Axial view showing a pneumatized anterior clinoid process.
The optic nerve is easily seen on endoscopy. (Blue Arrow Endoscopic View)
Blue Arrow indicates Optic Nerve

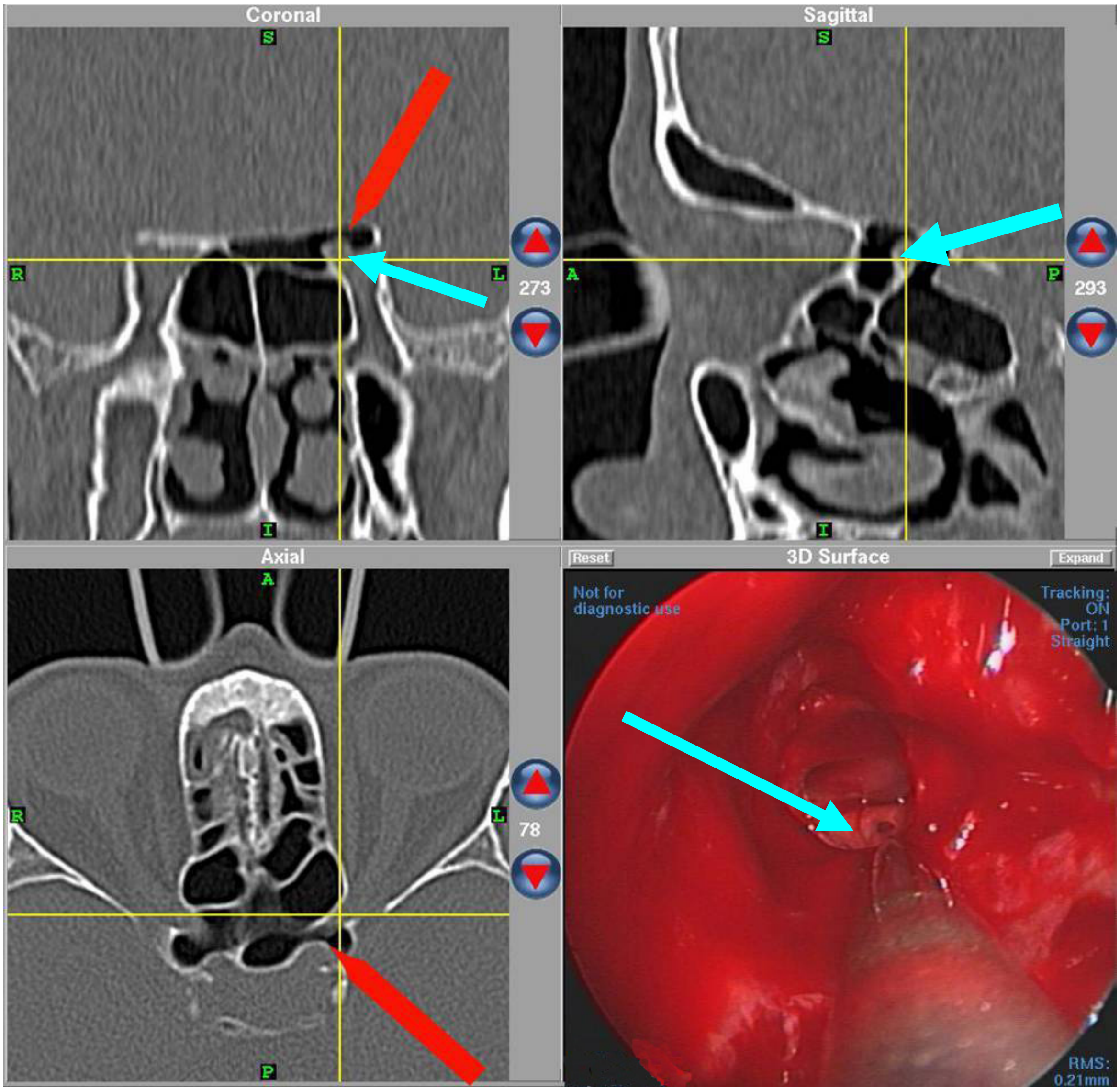

FIG 55

SPHENOETHMOID CELL AND THE OPTIC NERVE
TRIPLANAR CT IMAGES OPERATIVE VIEW
DEGREE OF PNEUMATIZATION IN THE VICINITY OF OPTIC NERVE.
OPTIC NERVE DEHISCENCE IN AN ONODI CELL. [4]

Blue Arrow Operative View shows the Optic Nerve in the Sphenoid Sinus.
Blue Arrow indicates Optic Nerve

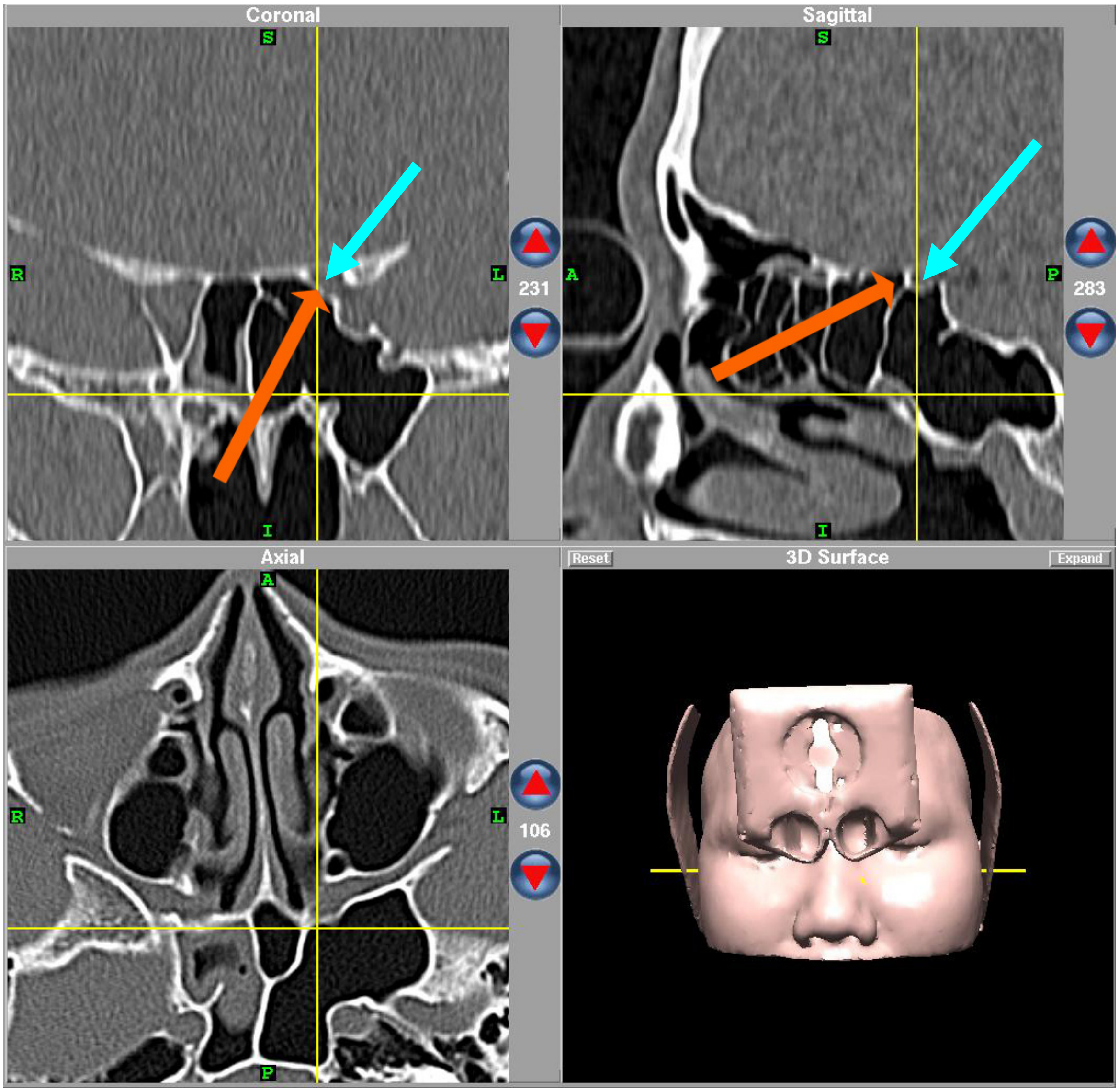

FIG 56

SPHENOETHMOID CELL AND THE OPTIC NERVE
TRIPLANAR CT IMAGES PLANNING VIEW
DEGREE OF PNEUMATIZATION IN THE VICINITY OF OPTIC NERVE.
SEPTAL INSERTION ONTO THE OPTIC NERVE IN AN ONODI CELL. [4]
Orange Arrow (Coronal and Sagittal).
Blue Arrow indicates Optic Nerve

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IMAGE GUIDANCE SYSTEM, INSTATRAK 3500.
For the illustrations presented Triplanar CT Views were obtained from a General Electric Connectstat Workstation used in Pre-Operative Planning and from the General Electric Instatrak 3500 system seen above for Operative Views.